The investigation of early classification of pressure ulcers using computer image analysis for early prognostic assessment

A thesis submitted in partial fulfilment of the requirements for PhD

By

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This research programme was carried out in collaboration with Queen's Hospital, Burton Hospital NHS Trust

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The Declaration

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Lastly but no means least to my mother and my daughter for understanding when Mummy is busy.

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Abstract

Pressure sore prevention is becoming a very important issue due to the cost of nursing time, quality assurance and possible litigation. Recent government reports Essence of Care (2001) and National Institute for Clinical Excellence Pressure ulcer risk assessment and prevention (2001) focus on pressure ulcers as a measurable outcome. Correct classification of the early stage of a pressure ulcer is essential, in order to instigate early interventions to prevent further pressure damage.

This thesis had four studies:

- The first study examines statistical evidence of the efficacy of two alternating mattresses. A randomised controlled trial of 141 Care of Elderly Patients who were assessed to have Torrance grade 2 and above pressure ulcers (71 on Cairwave, 70 on Nimbus 3). The secondary aim was to determine whether availability of extra pressure relief equipment would reduce the incidence of ulcers in an acute hospital.
- The second study investigated healing rates on the alternating mattress. This was measured using digital image analysis macro. Precision of image analysis assessed by within- and between-batch Coefficients of Variation was excellent: Calibration CV 0.93 - 1.84%; Area CV 4.61 - 5.72%.
- The third study was a descriptive study using a questionnaire and twelve digital photographs classified by 200 subjects using two

classification systems, the European Pressure Ulcer Advisory Panel and Stirling plus digits. The expert panel comprised of 5 tissue viability specialists / clinical lecturers in tissue viability with many years of collective experience were used as the gold standard to classify the questionnaire digital photographs.

- The fourth study used data from the original randomised control clinical trial of Pegasus Cairwave & proactive seating cushion and the Nimbus 3 & Aura seating cushion for the treatment of pressure ulcers. The data was examined to determine whether there are any common factors relating Hue Saturation and Intensity and a particular grade of pressure ulcers.

Overall, in studies 1 and 2 it was demonstrated that the Nimbus 3 was better at treating heel ulcers but both mattresses help treat sacral pressure ulcers at approximately the same rate.

The questionnaire demonstrated that there is considerable lack of consensus when pressure ulcers are graded using the Stirling plus digit grading system, and less disagreement when the EPUAP scale is used. Clinical Nurse Specialists in Tissue Viability were keen to receive extra education, whilst ward nurses were happy with their current knowledge and did not believe further education on pressure ulcers was required.

The final study demonstrated that the computer was able to identify early pressure ulcer formation with reasonable accuracy disparate. Using the information from the consensus panel, demonstrated a positive correlation between the computerized model and the panel's grades of pressure ulcers.

Null Hypotheses

Can pressure ulcers be assessed using a newly developed computer image analysis technique and can the results of the analysis be used to make a prognostic assessments enabling appropriate treatment to be initiated?

Is the assessment by image analysis superior to assessment by experienced specialist tissue viability nurses?

Is there a difference between healing rates on two different types of pressure relieving mattresses designed to treat pressure ulcers?

Is there a difference between two commonly employed pressure ulcer classification systems in terms of their complexity and accessibility by experienced specialist tissue viability nurses?

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Chapter 1

Introduction to Pressure Sore Prevention

Chapter 1

Introduction to Pressure Sore Prevention

1.1 Current National Perspective

Reducing the incidence of pressure sores - and optimising their treatment - is a key issue within the health service today. One of the aims expressed in the Government's Health of the Nation (1992) document is to reduce the incidence of pressure sores by between 5% and 10% annually. Commissioning authorities therefore expect providers to take positive action to minimise incidence, as do our patients. This document was the first to address the monitoring of pressure sores although it did not state how it recommended how the incidence was to be measured. The New Modern Dependable NHS (1997) discusses clinical effectiveness. Recent government reports Essence of Care (2001) and National Institute for Clinical Excellence Pressure ulcer risk assessment and prevention (2001) focuses on pressure sores as measurable outcomes, although standardisation of data collection would enable easier comparisons of similar client groups and hospitals.

The pain, suffering and even death caused by pressure sores is reflected in a marked rise in legal actions taken against health bodies throughout Britain over recent years. One case alone resulted in an out-of-court settlement of £40,000 (Collier 1995).

Pressure sore prevention is becoming a very important issue due to the cost of nursing time, quality assurance and possible litigation. An increasing variety of pressure relief equipment is on the market and the demand for it is continually growing. However, although there have been trials of the pressure relieving capabilities of different systems (Swain 1992), there have been very few clinical trials examining the efficacy of pressure relief equipment in actual patient care (Hitch 1994). Most studies that have been undertaken have only had small sample sizes and therefore could not provide a conclusive answer to the question of whether the equipment was effective for the treatment and prevention of pressure sores. This lack of controlled trials demonstrating the benefits of this expensive equipment is a problem for those providers who are attempting to choose between the huge array of products (Hitch 1994,Cullum 1995, Clarke 1997, Cullum 2000). In this review, the literature will be explored with reference to litigation cost of pressure sores, prevalence and incidence, nurse education and training, prevention of pressure sores, aetiology, risk assessment, grading of pressure sores, alternating pressure relief equipment, wound healing and nutrition, patient comfort and image analysis.

1.2 Costs of Pressure Sores

Pressure sores are the "Silent Epidemic under the Sheets" and over the last few years. This epidemic has come to the attention of both nurses and the public (Richardson 1992). This epidemic will increase over the next few years as the number of people age 65 years and over will increase from

16% to 20.4% by the year 2031 (Henwood 1991, Office of Health Economics 1992, Bank 1997).

Hibbs (1987), Waterlow (1988) suggest that 95% of pressure sores are preventable and only 5% of pressure sores are not preventable due to the patient's condition prior to admission eg lying on hard floor. Despite this there is no evidence to prove this statement is correct. A pressure sore affects almost one in ten patients. Pressure sores are estimated to cost the Health Service between £300,000 and £750,000 a year per Health District (Dealey 1994). The estimated cost of developing pressure sore is £300 - 350 million and is predicted to cost £14000 per patient (Waterlow 1988). These costs are increasing due to inflation and litigation case settlements of between £100,000 and £250,000 (Moody et al 1991).

Hibbs (1988) demonstrated costs with a case study of a 75 year old patient who was nursed with a fractured femur and who had sustained a grade IV pressure sore (an ulcer that extends into the subcutaneous fat) after surgery. The cost was calculated at £25,905.58 for 180 days treatment as an in-patient. This was not only a "lost opportunity for the patient" but also deprived other patients of treatment, as the total cost would have paid for 21 standard orthopaedic operations.

Cave & Descombes (1998) suggests that money is being wasted on costly mattress rentals as hospitals are not analysing the cost and benefits of equipment and this is costing the National Health Service millions of pounds. Hospitals should also investigate the merits of buying and hiring special equipment in relation to pressure sores reduction. Finally it has been suggested that the Department of Health should produce "best buy guides" for equipment. Where a Tissue Viability Nurse is in post, I would suggest that money should be no longer wasted as pressure-relieving equipment is monitored closely, particularly with the aim of reducing the incidence of sores. A guide to the best equipment would be ideal but would be controversial because the effect on manufactures. A guide to equipment does exist from the Medical Devices Agency on Static Mattress but only applies to alternating systems and seating cushions. This guide includes evaluations, which give the interface pressures, which are only a token measure of the effectiveness of the equipment.

Fuchs (1990) states that a well-designed and executed randomised controlled trial has been described as the " ***crown jewel of technology assessment*** ". However, unfortunately this type of data is not available for pressure relief equipment.

1.3 Litigation

The increasing frequency of litigation cases arising as a result of pressure sores poses the question: "Who ultimately takes responsibility for the cost?" The United Kingdom Central Council Code of Professional Conduct asked the question: "Can the development of a pressure sore in a patient under a nurse's care be considered as failure by the nurse to execute her duty and is the nurse legally or morally culpable?" (Moore 1987). Nurses, therefore, should be aware of the code of conduct which requires "that no action or omission in care is made which is detrimental to the condition or safety of the patient". Failure to assess, record and take appropriate action in the prevention of pressure sores amounts to unethical nursing practice (Moore 1987). Nurses need to be able deliver the highest standard of care, to uphold professional values, and not to have to live in fear of litigation.

Pressure sores are performance indicators and are related to quality assurance issues that can be measured by research and monitored by prevalence and incidence studies (Robertson 1987). Recommendations have been made that each District should develop a policy for the prevention and treatment of pressure sores, not only for ethical and professional reasons, but also for legal and economic uses (Hibbs 1987).

Despite the increasing costs of pressure sores, only one report has been commissioned by the Department of Health into the cost (Touche Ross & Co 1993 Pressure Sore A Key Quality Indicator). The costs of preventing pressure sores in a 600-bed hospital were estimated at between £600,000 and 3 million a year. Dealey (1997) suggests that there are number of faults in these estimates as the costing of preventing pressure sores also includes staff education and employment of a Tissue Viability Nurse. The document assumes that treatment takes less time than prevention when in fact if prevention is carried out early enough it is cheaper (Waterlow 1988, Dealey 1997).

One of the biggest difficulties when trying to attribute the cost of pressure sores is separating out prevention from other treatments e.g. malnutrition and immobility. Treatment often includes costs incurred whilst in hospital regardless of having a pressure sore (National Pressure Ulcer Advisory Panel 1989, Hitch 1995).

1.4 Prevalence and Incidence

The "Health of the Nation" (1992) discussion document states that prevalence of pressure sores in hospital patients in the UK is 6.7% these figures were derived from (David *et al* 1983). The Government's view is that an annual reduction of at least 5-10% in their incidence would be a reasonable target. Clearly, the first task for Health Authorities would be to establish a base line for the incidence and prevalence of pressure sores. Many hospitals have now established a prevalence rate, and some an incidence rate, through continuous audit. Prevalence and incidence, which yield different results and are not to be confused, and are both valid ways of obtaining information (O'Dea 1993). These figures are usually expressed as percentages of a total population and are used as quality indicators and guidelines for establishing the necessary resources, e.g. Tissue Viability Nurses.

- **Prevalence refers to the presence of both old and new cases, assessed on *a cross section at one particular time.* (O'Dea 1993)**

- **Incidence refers to new cases occurring over a given period of time, *usually involving* a particular patient population. (O'Dea 1993)**

The total population selected for the sample for the incidence and prevalence may have an effect on the percentage. Simple inclusion or exclusion of a high turnover area such as a day surgery unit or a low risk unit such as maternity can significantly alter the end result of six-month incidence. Comparability of client population can vary as it could be argued that a teaching hospital treats more acutely ill patients than a general hospital. The general hospital may state that it has a higher caseload of chronically ill patients who are at risk for longer periods (Fletcher 1997).

Healey (1994) suggests that Trusts that are accurately reporting their prevalence rates may compare poorly against Trusts that are not factually reporting data due to their inadequate method of collecting data. This may lead to Trusts being reluctant to collect data for fear the purchasers may look elsewhere if the incidence appears to be high (Hampton 1996). However a greater threat is likelihood of the government will try to create league tables with the information submitted to purchasers despite the different client population within each hospital.

O'Dea's study (1993) involved multi-site trials in the UK and collected data from 3,213 adult in-patients excluding obstetrics and acute psychiatry. Staff were trained in the method of data collection and patient assessment and in the different stages of pressure sore grading. The Waterlow Score risk assessment tool was used to provide a profile of patients at risk. It was demonstrated that there was a high prevalence rate of 18.6%, in contrast to the published Department of Health figure of 6.7% (1992). Approximately a third of all in-patients should have had a care plan, including all aspects of prevention and damage, but 52% of patients with established pressure sores did so. A striking fact was the lack of a systematic approach to prevention and treatment, even when lengthy protocols have been produced. This was indicated by the low priority given to documenting a care plan for prevention and treatment. This, of course, does not imply that nurses are not giving conscientious care to those patients at risk, but that they would have been unable to demonstrate that they had planned and delivered the proper care and evaluated its effectiveness.

1.5 Nurses Education and Training

Gould's (1992) study on "Teaching students about pressure sores" surveyed nurse tutors and in-service education in 13 Colleges of Nursing, randomly selected from the North Thames Region. The aim of the study was to determine aspects of prevention and treatment and how they were taught, and why material was selected and its relationship to research. It revealed that pressure sore prevention received a low priority and was only included in the introductory period and never updated or revisited. Most of the knowledge gained by students was under the auspices of the qualified staff. Few tutors were aware of textbooks available on the subject. The in-service education department's response was very poor. Pressure sore prevention was not worthy of inclusion for updating, as managers considered it a low priority, especially where there was a lack of funds available. Tutors directly responsible for teaching had only a vague or superficial knowledge of pressure sores. Responsibility, therefore, lies firmly with the nurse teachers themselves who should collaborate with teachers in higher education and their clinical colleagues before planning and implementing educational programs.

The reading habits of registered nurses practising in a hospital setting were surveyed by Skinner & Miller (1989) when 991 nurses were asked to complete a questionnaire consisting of 26 items of open ended questions. Analysis of 507 questionnaires returned indicated staff nurses valued nursing literature as a means for keeping in touch with developments in the profession and perceived that information in Nursing Journals helped in their clinical practice. As professionals, nurses have a responsibility to keep abreast of research by reading published papers and articles in medical journals. It appears that some nurses purchase journals themselves, as only one copy may be available in hospital libraries.

However, if journals were freely available in the work area the nurses would have easy access to current research.

Hill's (1992) study on nurses knowledge and practice of pressure sore prevention, was in two parts. The first part was a continuous non-participant observation for five shifts on how pressure area care was delivered to patients identified as being at risk. The second part was a questionnaire completed by nurses working on these wards to assess their knowledge of pressure sore prevention and any factors, which they felt, restricted their delivery of patient care. It demonstrated that nurses did not use their knowledge of preventative dressings or nutritional assessment. They failed to implement their knowledge of pressure risk, reassessment, turning regimes, washing incontinent patients and pressure relief. Some misguided practices, such as the massage of pressure areas, were advocated. Nurses were unfamiliar with the correct use of pressure relieving aids and beds. Their lack of knowledge could be attributed to, poor staffing poor educational provision and insufficient equipment. A definite need for education was demonstrated and it was suggested that this should take place during training, and that it should be continued after registration by the use of study days.

Gould (1986), Dealey (1989) suggest that " there is no excuse for nurses lacking up to date knowledge of pressure sore prevention and treatment. Currently there are frequent study days that provide this knowledge and these are often free apart from the time to attend the event. Ibbotson's

(1991) study demonstrated a need for more pressure relieving equipment and instruction for nurses on how to use the equipment. Most companies provide education on how to use their products.

Russell (1996) explored nurse knowledge and practices in pressure area care. 48 care plans were audited with 17 closed questions to ascertain which patients were "At Risk" using the Waterlow Score. Nurses were assessed using a questionnaire of a mixture of opened and closed questions to explore their reading habits, and knowledge of prevention, predisposing factors, education, assessment scales, grading scales, special mattresses, planning and implementing and evaluating patient care. It was demonstrated that better post basic education was essential in order to improve the quality of patient care. Very few nurses had attended study days, but many would have liked the opportunity to learn more on pressure sore prevention. A pressure prevention policy should be audited through prevalence so that effectiveness can be measured.

The King's Fund (1989) Pressure Sore Study Group suggests that nurses' knowledge should be expanded by study days arranged by the District. A key person should be encouraged to attend conferences, exhibitions, and join relevant societies and keep abreast of published research thus acting as a resource educationalist for the hospital. (King's Fund Pressure Sore Study Groups 1989, Moody et al 1991).

1.6 Conclusion

The government has placed the emphasis on demonstrating Clinical Effectiveness and pressure sores are measurable outcomes. There is no nationally agreed formula for this data to be collected. Some trusts are currently just collecting prevalence and some collect both incidence and prevalence. At least some areas are collecting this data which does allow comparisons from year to year allowing for hospitals activity. Demographic changes of an increasing elderly population mean the number of patients at risk will increase considerably in years to come. Money is being wasted due to a lack of randomised control trials to demonstrate the effectiveness of pressure relieving equipment, but companies are now starting finance research into their equipment. Government grants are also a source to finance research on Clinical and economic elevation of equipment.

Litigation costs are increasing and majorities of cases are settled out of court. Every Trust should have pressure prevention guidelines. Alongside this, education is required in the prevention and treatment of pressure sores. Numerous study days are available for nurses to update on. Pressure sores are not just a nursing problem and the multi-displinary team needs to be involved in their management, as *Pressure sores are everybody's responsibility!*

Chapter 2

Physiology Of The Skin And Prevention Of Pressure Sores

Chapter 2

Physiology Of The Skin And Prevention Of Pressure Sores

The prevention of pressure sores has always been a nursing role. Florence Nightingale believed that pressure sores could be prevented by good nursing care (Smith 1992, Abel-Smith 1960). Doctors have always regarded pressure sores as a nursing problem. Indeed, Charcot considered that "doctors could do nothing about them" (Dealey 1991). These attitudes resulted in nurses carrying the burden of treating sores instead of establishing and eliminating the cause of the problem. The key to successful prevention is the relief of pressure. There is sound practical sense in the adage " you can put anything on a pressure sore except the patient" (Witkowski 1986). Nurses deliver skin care and assist in patients' hygiene needs. This provides them with the ideal opportunity to assess the patient's skin condition to determine if the use of pressure relief equipment is required.

It is essential that nurses have an understanding of the physiology of the skin to enable comprehension of the development of pressure sores. The development and cause of pressure sores is multifactorial. Despite a great deal of research on the aetiology of pressure sores, the mechanism and circumstance of how they occur are not fully understood.

2.1 The Physiology of the Skin

The skin is a very complex organ and is one of the largest organs in the body. It can reflect a person's state of health e.g. if the skin is flushed or pale. In the average adult the skins' surface total area is 1.8 m^2. The skin varies in thickness depending on the requirements of the particular area of the body, the thickest areas being the soles of the feet and palms of the hands (Collins 1998).

The main functions of the skin are:

♦ To maintain the body's temperature through vasodilation and constriction of the surface blood vessels.

♦ Protection from friction and shear, dehydration , ultra violet light and radiation

♦ Perception of temperature, pain and touch

♦ Excretion of small amounts of salts and perspiration (assists thermal regulation)

♦ Synthesis of vitamin D.

♦ Prevention of loss of water and electrolytes.

The structures of the skin can be broken down into two principal layers,: epidermis and dermis (fig 2.1). There are five layers in the epidermis composed of: stratified squamous epithelium, keratinocytes, melanocytes, Langerhan cells and Granstein cells (which are associated with immunity) (Tortora & Anagnostakos 1987) .

2.1.1 Stratum Basale

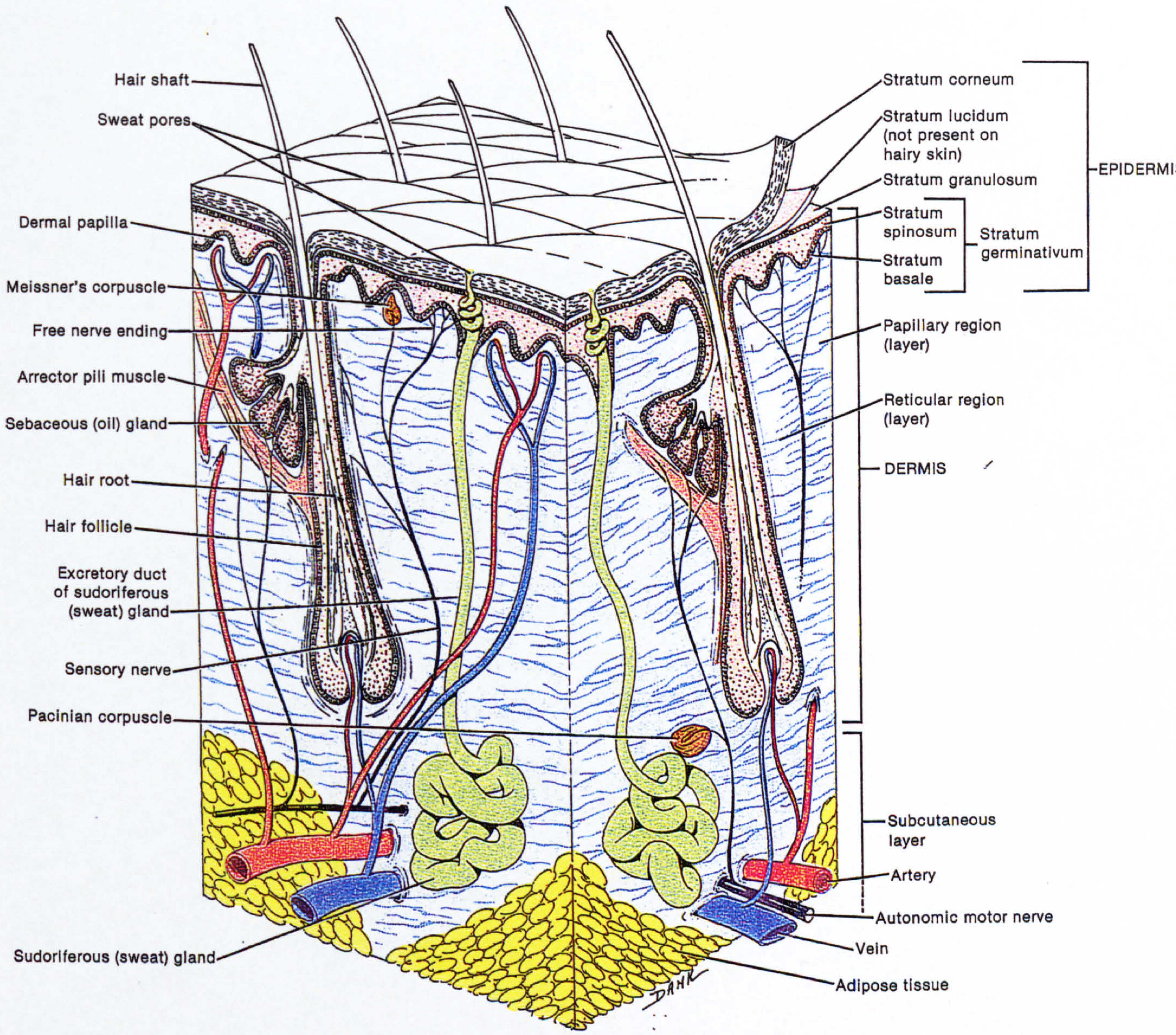
This is the deepest layer of the epidermis and consists of basophilic columnar or cuboid cells which rest on the dermal-epidermal junction that separates the dermis from the epidermis. This layer is characterised by intense mitotic activity and is responsible, in conjunction with the initial portion of the next layer, for the constant renewal of epidermal cells. The human epidermis is renewed about every 15-30 days depending on the region of the body, age and other factors. (Junqueira *et al* 1977). These cells acquire their oxygen by diffusion or active transport from the capillary networks in the dermis. (Collins 1998).

2.1.2 Stratum Spinosum

This part of the skin comprises of 8-10 rows of cells providing opposition to mechanical disruption. This layer consists of cuboid polygonal or slight flattened cells with a central nucleus and a cytoplasm with processes filled with bundles of fibrils. This layer is held together by small cellular extensions called desmosomes and these are linked to the spinosum and cover the whole surface. These give a prickly studded appearance to the cell when seen under a microscope. Within this strata are nerve endings for sensation and touch. The bundles of fibrils visible under the microscope are called tonofibrils (fine filaments) and are believed to form into cellular bridges which unite cell to cell.

Fig 2.1

The structure of the skin



Adapted from Tortora &Anagnostakos (1987)

The filaments are the main precursor of keratin and spread throughout the cytoplasm and extend into the intercellular ridge to converge at the desmosome (Junqueira *et al* 1977).

2.1.3 Stratum Granulosum

This layer is three to four layers of flattened polygonal cells containing centrally located nuclei and cytoplasm. Keratohyatin is contained within this structure and gives colour and waterproofing to the epidermis (Junqueira *et al* 1977).

2.1.4 Stratum Lucidum

These flat dead cells are found on the palm of the hand and the sole of the feet. These are translucent and composed of a thin layer of flattened eosinophilic non-nucleated cells (Junqueira *et al* 1977).

2.1.5 Stratum Corneum

There are 25-30 flat dead cells containing keratin and are constantly being shed. This layer is tough, water proof and acts as a barrier against bacteria and chemicals. These cells are constantly being worn away and replaced. This process takes between 15-30 days (Junqueira *et al* 1977, Collins 1998).

2.1.6 Dermis

Below the epidermis, this layer comprises of blood vessels, nerves, glands and hair follicles. These structures area held in position by strong connective tissues, collagen and elastin. This layer is further divided into an upper stratum named the papillary region and contains the Meissner's corpuscles (the nerve endings responsible for touch). The deeper layer is the reticular region comprising of capillary loops and a matrix of collagen and elastin which are used in temperature regulation, excretion, and acts as a cushion from physical and mechanical damage (Bridel 1993). This layer also contains the Pacinian corpuscles which are nerve endings sensitive to pressure. It would be these endings which inform you to relieve pressure when you sit in one position for a long time.

2.2.The Aetiology of Pressure Sores

It is well-established that pressure sores are due to a combination of extrinsic and intrinsic factors (Bridel 1993, Bliss 1993). Dealey 1997 further classifies the origins of pressure sores into three categories: intrinsic, extrinsic and external factors.

2.2.1 Extrinsic

There are three extrinsic factors which predispose to pressure sores, either on their own or in conjunction with each other.

- **Pressure**
- **Shear**
- **Friction**

2.2.1.1 Pressure

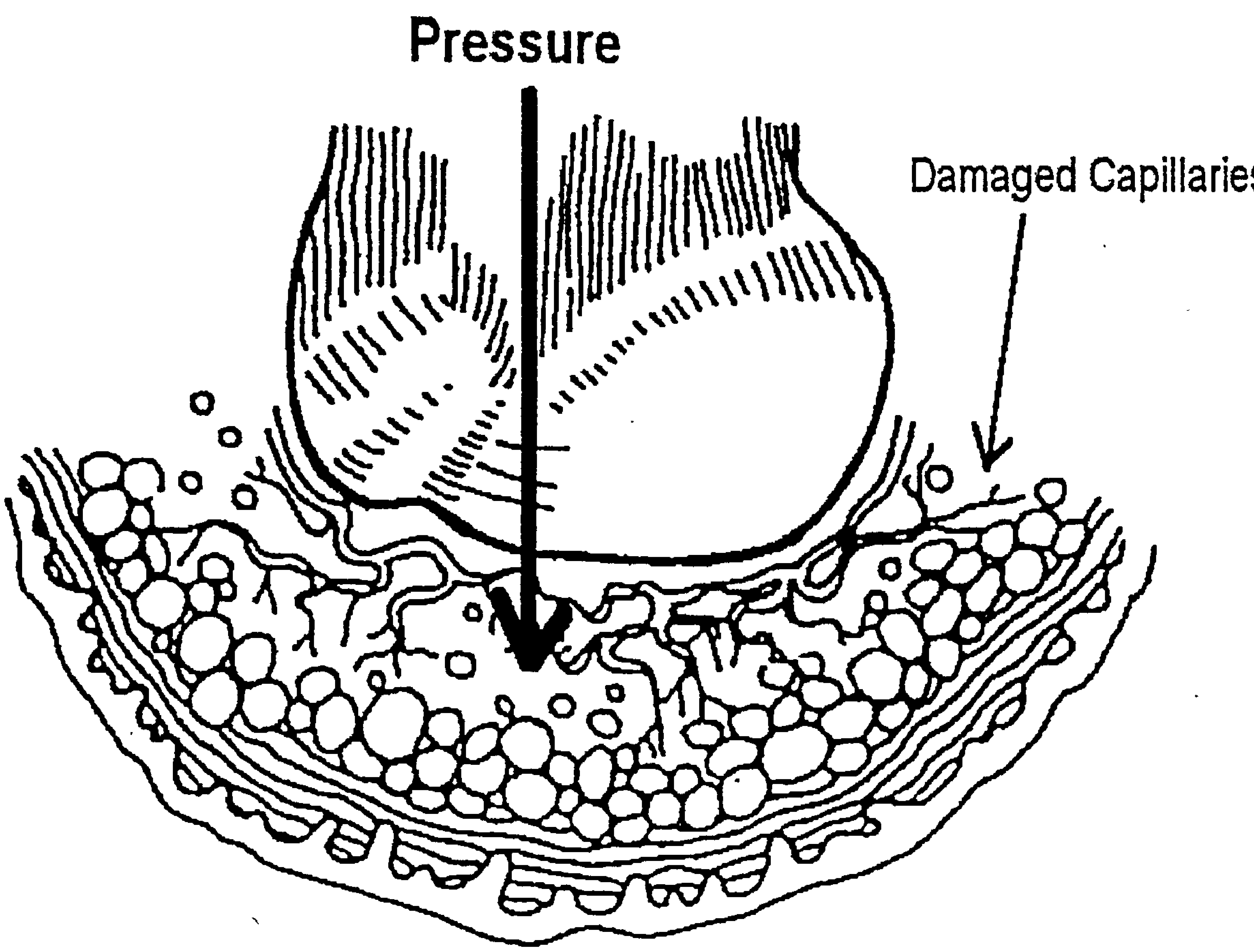
Pressure occurs when soft tissue over a bony prominence is compressed between a hard surface and the bone. The resultant pressure can be greater than the capillary pressure, and may result in localised ischaemia (figure. 2.2). When the pressure over an ischaemia area is relieved, a red area appears over the bony prominence as a result of the blood supply being temporarily increased for the removal of waste products, and supply of oxygen and nutrients. This is called *"REACTIVE HYPERAEMIA"* (Dealey 1994).

The importance of being able to recognise reactive hyperemia as a precursor to the development of pressure sores is crucial (Bridel 1993). Pressure sores originate in the deep subcutaneous tissues when the external pressure on the capillary exceeds the mean capillary pressure of 25-33mm Hg - (in the elderly, this threshold may be as low 6mmHg (Landis 1931).

However, literature on the present threshold is unclear and many issues still need to be investigated. When the duration of occlusion of the capillaries is excessive the blood supply ceases, tissue dies and a pressure sore results. If the patient is in shock this occurs rapidly due to the lowering of the blood pressure and capillaries shutting down. The closing down of microcirculation leads to oedema and micro thrombi of the

Figure 2.2.

Skin damage caused by compression against a hard surface.



Adapted from Collier (1990)

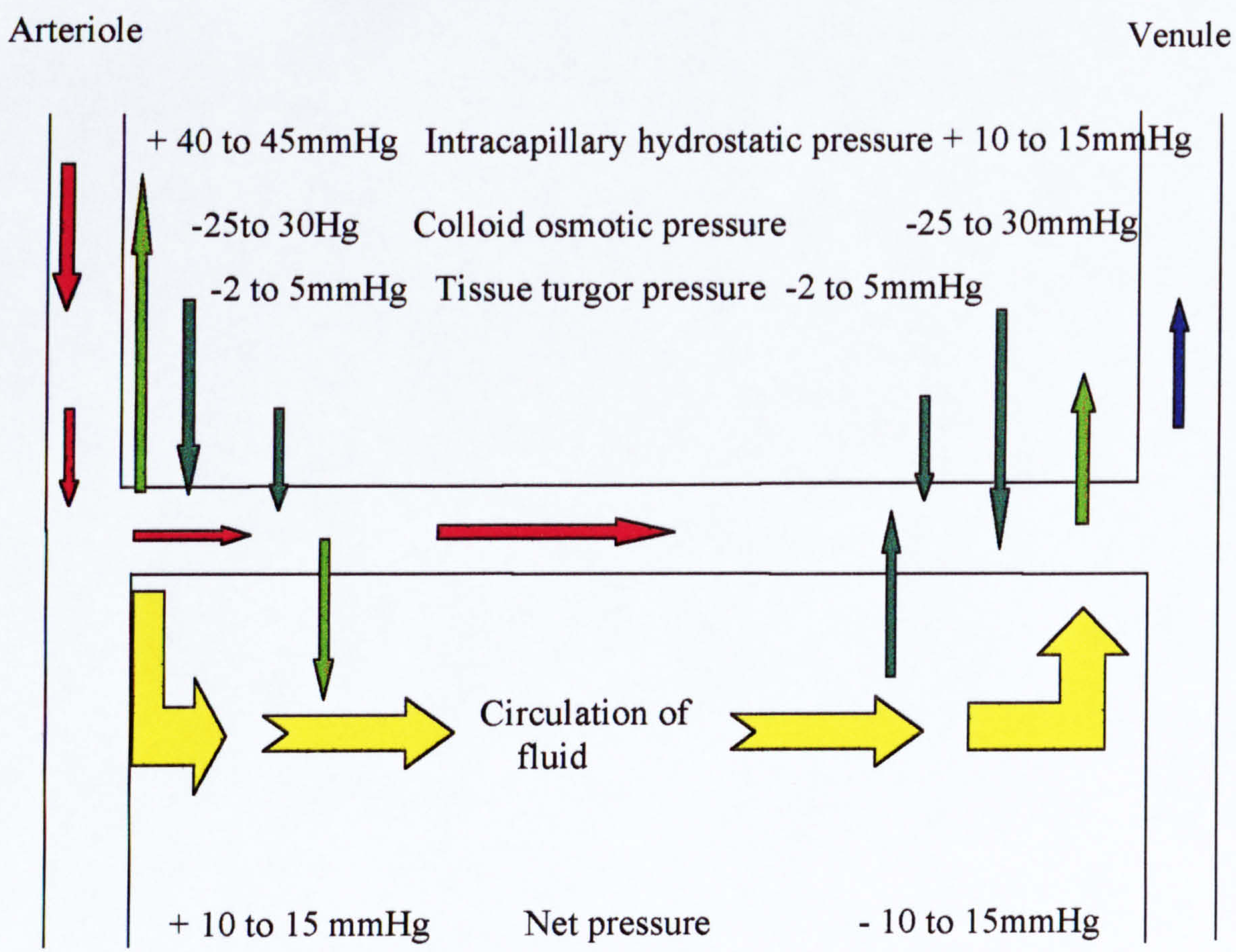
vessels. This causes erythrocytes, platelets and leucocytes to clump together leading to leakage of exudate into the tissues. This in turn may cause the basal cells to separate with progression to destruction of the dermis, sweat glands and hair follicles (Waterlow 1988). The process governing formation of oedema is covered by Starling's hypothesis (Figure 2.3).

Oedema occurs when there is an imbalance when the outward forces exceed the inward forces and which produces an excessive accumulation of interstitial fluid. However oedema does not occur until there is large imbalance in these forces acting at the capillary walls (Hincliff & Montague 1996). This explains why not every patient with a pressure sore has oedema present. There are many causes of oedema and some of these factors are linked with the development of pressure sores. A patient that is malnourished may have low plasma protein and this can lead to porous capillary walls giving rise to oedema. There is no clear evidence of the role in which oedema plays in the formation of pressure sores and further research does need to be undertaken.

Landis (1931) measured capillary blood pressure in human skin. This demonstrated the average capillary closing pressure is 32mm Hg. The capillary bed pressure at the venule end is 12 mm Hg. These readings are not surface pressure but intra - capillary pressure. Additionally Landis commented " capillary pressure is not constant , it changes from

Fig 2.3

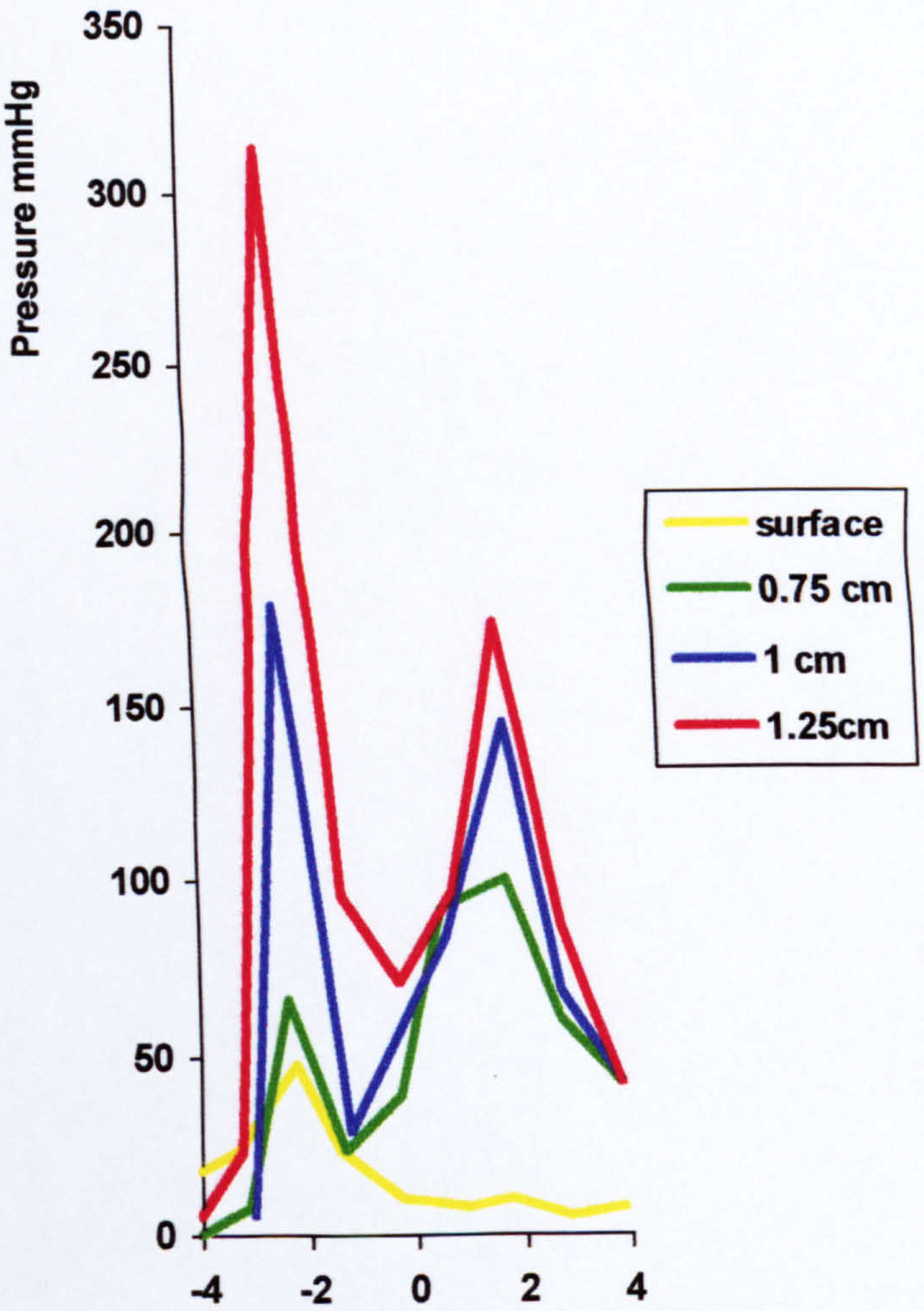
Starling hypothesis of fluid distribution between blood plasma and interstitial fluid compartments



Adapted from Mountcastle 1974

Figure 2.4

Internal pressure may be 3-5 times greater than the surface pressure



Approximated graph of the pressure distribution sampled at different planes in tissue underlying the left trochanter and the ischium and pressure distribution measured at the surface. Taken from Le et al. (1984).

individual to individual". Le et al (1984) investigated the tissue at the skin surface and discovered that surface pressure may remain below 25 - 32 mm Hg but internal pressures were sufficient to impair capillary flow because internal pressure may be 3-5 times greater near a bony prominence (Fig 2.4). Bridel (1993) suggests that Landis' view of the microcirculation is insufficient, as it does not take into account the protective effects of collagen which acts as a buffer to external pressure. The collagen content of the dermis alters with age or disease. Therefore the figure of 32mmHg will differ from individual to individual.

Lowthian (1982), Kroupkop (1983) and Bridel (1993) discussed, the importance of distinguishing when occlusion causes a necrotic pressure sore, age or disease. Therefore the figure of 32mmHg will differ from individual to individual. As there are many factors involved in the formation of pressure sores, pain, sensation, circulation and lymphatic impairment.

Kosiak (1961) confirmed that there is connection between pressure and time and that pressure exceeding 200 - 500mm Hg at heart level will produce necrosis in a short time period. However, it is not precisely known how long it takes for a pressure sore to develop. Kosiak (1961) concluded that " since it is impossible to completely eliminate all pressure for a long period of time, it becomes imperative that the pressure be completely eliminated at frequent intervals in order to allow circulation to the ischaemic tissues". Lowthian (1995) found that 40 - 45 mm Hg may take

50 - 60 hours to produce pressure damage. He concluded this probably is the maximum time that the skin can withstand simple ischaemia. However, simple ischaemia fails to answer how serious deep sores can occur in just matter of a few hours of immobility. Daly *et al* (1976) suggests that the soft tissue becomes increasingly deformed under sustained loading point. When sufficiently distracted, the microvasculature structures becomes overstretched and partially torn producing multiple microthrombi (Lowthian 1995 b). Thus the appearance of areas of necrosis, particularly over bony prominences are believed to be precursors to deep pressure sores.

A study by Reswick & Rogers (1976) is still referred to and cautiously defines the "acceptable pressure time limit" which ranges from 2-18 hours and 100-700mm Hg of pressure/time over a bony prominence. Lowthian (1997) suggested that a new pressure/time curve needs to be designed for a patient in bed as the measurements were designed for wheelchair users who have no sensation below the waist and concluded that " if we could be more precise about the length of time that various AT RISK patients can safely maintained, i.e. nursing position or wheelchair, we should be able to reduce the incidence of serious pressure sores."

2.2.1.2 Shear

Shear forces are one of the most dangerous problems facing a patient who is being nursed semi-recumbent or in a chair. Shearing forces produce destruction of the micro circulation by thrombosis of the vessels and occur when the patient slips down the bed, or if their heels are dragged on the bed whilst being lifted up (Versluysen 1986, Waterlow 1988). In the case of seated patients, gravity pushes the body down encouraging the patient to slump and slide down the chair.

Lowthian (1997) stated that it is practically impossible to measure with confidence, the forces involved in pressure sore formation. It is exceptionally difficult to measure static friction and shearing of the skin.

2.2.1 3 Friction

Friction can be described as the resistance of one surface to another moving over it. Friction must also be considered as it causes stripping of the skin leading to superficial ulceration on such areas as heels and elbows (Waterlow 1988). This occurs when two surfaces rub together and results in the top epithelial cells being scraped off and leading to superficial ulceration on heels and elbows (Waterlow 1988, Dealey 1994). An example of this is when a patient is returned to a sitting position in bed (figure 2.5). When the people lifting, slide the patient rather than ensuring they are lifted clear of the sheet. When this occurs, friction will take place at the skin's surface.

Walsh and Ford (1989) comment on a strange ritual of rubbing the buttocks to improve the circulation. This was first advocated by Hughes

(1899) who stated that in all cases the rubbing should be very thorough, so as to improve the circulation. It has also been suggest that standing the patient up and giving the buttocks a "good rub" to get the circulation going actually did more harm than good as the surge of blood supply to the occluded area caused tissue necrosis (Olson 1992). Dyson (1978), Bailey (1984), Bliss (1985), Redfern (1986) have all commented that excessive massage could cause tissue damage. Pritchard and Mallett (1993) state that massage causes skin maceration and degeneration of subcutaneous tissue; especially in elderly people. In spite of this Eliopoulous (1993) advises that the edge of pressure sores should be massaged and Kanazawa (1990) stated that massage should form part of preventative care whilst Windmill (1992) announced that massage encouraged circulation.

Massage of the skin is still controversial: Anthony (1996) showed that no positive effects from massage have been demonstrated but no experimental studies have been undertaken to fully investigate the effects. Even where short periods of massage have been monitored the effects were damaging and therefore, longer periods of massage would be distinctly dangerous.

2.2.2 Intrinsic Factors

Patients are more vulnerable to pressure sores as a result of:

- loss or reduction in mobility,
- neurological injury
- pain

- sedation
- reduced levels of consciousness
- severe or terminal illness
- circulatory disorders.
- Incontinence

2.2.2.1 General Health

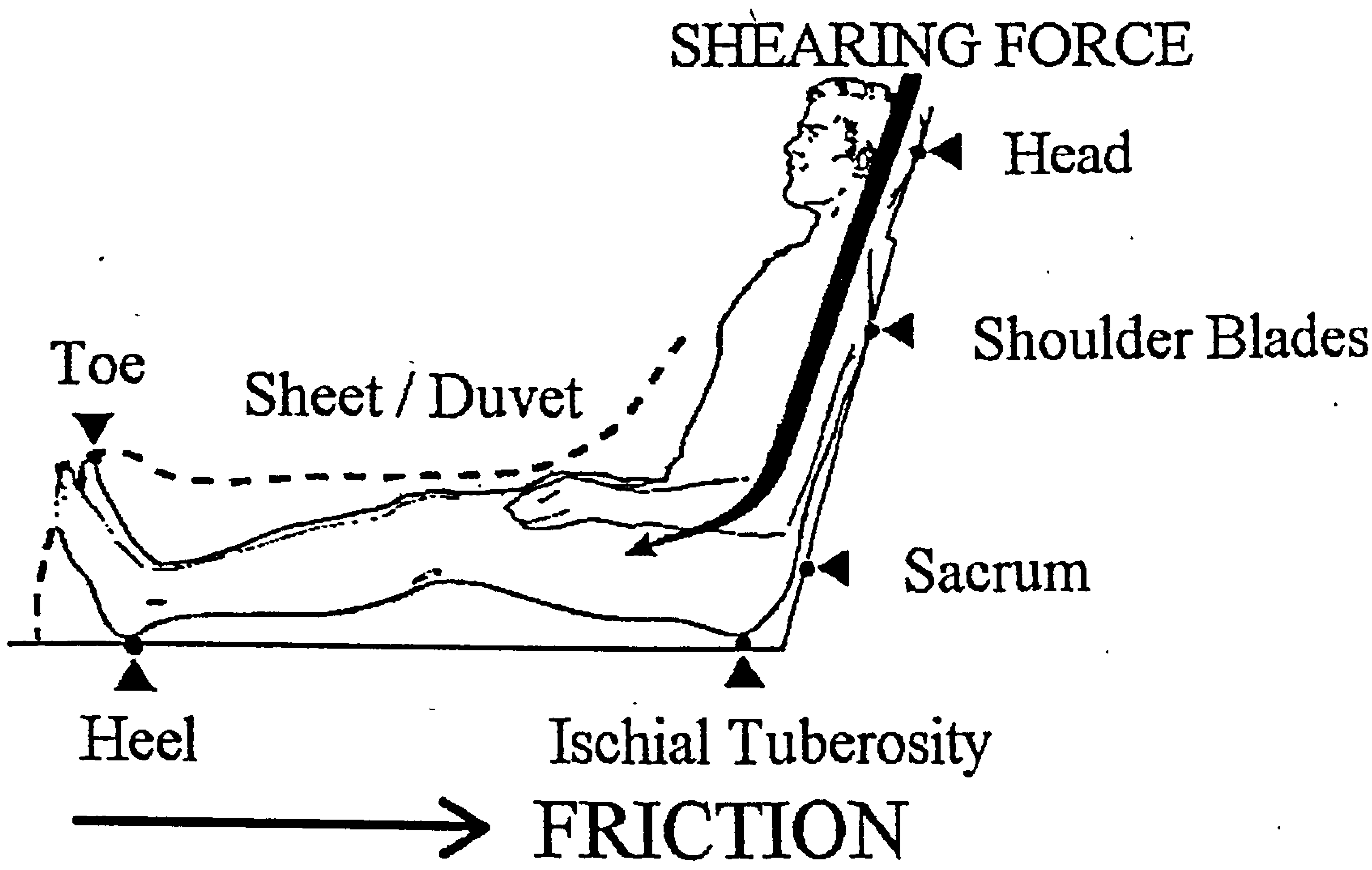
Bliss (1990) suggests that the acutely ill are particularly vulnerable, possibly due to precipitating factors such as pain, low blood pressure, heart failure, vasomotor failure, peripheral vasoconstriction due to shock and others. Barton (1985), Clark & Farrar (1991) state that the majority of pressure sores occur within the first two weeks of hospitalisation, and it is likely that this coincides with the acute phase of their illness. People suffering with chronic diseases, and elderly people who live alone, may eat small unbalanced meals which lack vitamins and minerals. Lack of money, weakness and depression can also contribute to the problem of a poor general state of health (Morison Convatec 1993).

2.2.2.2 Age

A survey by David et al (1983) discovered that 85% of patients with pressure sores were over 65 years old. This may be due to thinning of the dermis, which leads to decreased elasticity of the skin and increased risk of pressure sores. The collagen in the dermis provides a buffer which helps to prevent disruption of the micro circulation (Kroupskop 1983). Also, it takes longer for a sore to heal in the older person when compared to a younger person. As age increases so does the likelihood of chronic illness which also predisposes to development of pressure sores.

Figure 2.5

Patient in semi recumbent position and the forces of friction and shear



Adapted from Torrance (1983)

2.2.2.3 Reduced Mobility

There may be numerous reasons why a patient has decreased mobility: neurological deficit such as paraplegia, multiple sclerosis, diabetes and spinal injury or degeneration, or a major operation. Reduced mobility has been identified in increasing the risk of pressures developing (David *et al* 1983, Dealey 1997).

2.2.2.4 Decreased Consciousness

Brown (1985) demonstrated a strong relationship between reduced movement and the development of pressure sores. Therefore, confused patients on antidepressants and opioids who may not move of their own accord and relieve their pressure areas that are at increased risk.

2.2.2.5 Bodyweight

Emaciated patients have no 'fatty padding', particularly over the bony prominences, and so have less protection against pressure sores. However, very obese patients are also at high risk as they are difficult to lift in bed and may be dragged resulting in increased shear. Additionally when obese patients sweat, the fluid becomes trapped in the rolls of fat causing the skin to become macerated. Furthermore, both extremes of patient may have poor nutritional status (Dealey 1997).

2.2.2.6 Incontinence

Moisture is a factor which increases the risk of pressure sores, particularly if friction and shear occur (Torrance 1983). Urine and faeces are known to lead to skin maceration and excoriation, which leaves the skin vulnerable to friction and shear (Flanagen 1993). Additionally, constant washing removes the body's natural oils by drying the skin (Jordon & Clark 1977).

2.2.2.7. Nutrition

A balanced healthy diet is not only essential for health but also to maintain skin integrity. The benefits of good nutrition status are often overlooked (Liyanage – Johnson 1995). One reason why malnutrition is often unrecognised is that doctors and nurses are not used to looking for it (McWhirter & Pennington 1994). Also, nutrition and malnutrition are not always included in professional training curricula and so the symptoms of malnutrition may not be noticed by the ward staff (Bond 1998). Nutrition plays a very important role in the formation of pressure sores. It is well researched that patients are often malnourished on admission to hospital and, therefore, when an elective admission is planned encouragement to take adequate diet prior to admission is necessary (Bond 1998). Of course this does not take into account the emergency admissions. Which anecdotally often patients are even more poorly nourished. Often patients have a poor understanding of a balanced diet, and careful assessment needs to be made to ascertain whether the patient is eating an AVERAGE diet (e.g. three balanced meals per day) or a POOR DIET (one to two inadequate meals per day).

2.2.2.8 Poor Blood Supply

Patients who have poor oxygen perfusion due to heart disease, peripheral vascular disease or diabetes have a lower peripheral capillary pressure. Jointly these cause tissue malnutrition (Dealey 1997). Drugs may also cause peripheral vasoconstriction and reduce the patient's mobility.

2.2.3 External Factors

The external factors may exacerbate some of the extrinsic or intrinsic factors that can contribute to pressure sores. For example, correct lifting every two hours must always be considered. Damage can be avoided by ensuring good tissue perfusion by repositioning at least every one to two hours. The precise time interval is not known.... Poor lifting and handling technique can result in a patient being dragged up the bed rather than lifted (Dealey 1997). Hard chairs, trolleys and commodes may also cause friction on the skin. Unsuitable clothing that is too tight or difficult to undo can result in trauma on removal. Patients who are wheelchair dependent should ideally wear garments that are practical as well as fashionable. It is well known that diabetic patients should not wear tight shoes and neither should patients with loss of sensation. Poor hygiene also has to be considered as a patient being sat in urine or faeces for a long period of time will contribute to skin maceration and break down. Dealey (1997) states that moisture increases friction forces.

2.3 Conclusions

Over the next few years as the number of people age 65 years and over will increase from 16% currently to 20.4% by the year 2031 (Henwood 1991, Office of Health Economics 1992, Bank 1997). This will mean that the number of people at risk of pressure sores will increase. It is known that age does play a key role in the development of pressure sores because of loss of skin elasticity, collagen and increased episodes of chronic illness. Additionally there are still many factors that contribute to the development of pressures that can not be determined and further research is required: the precise time it takes for a pressure sore to occur; the role of oedema and why it is present in some pressure sores and not others; etc. Furthermore, how can friction and shear be prevented.

A sound knowledge of the physiology of the skin and how to prevent pressure sores is fundamental to patient care. The best insurance for the safety of these patients is prevention from the moment they are admitted into our care. Prompt prevention of pressure sores is not only economically sound but ultimately results in high quality patient care.

Chapter 3

Classification Systems

Chapter 3

Classification Systems

3.1 Development of Classification Systems

3.1.1 History of Classification Systems

During the last 30 years many classification systems for pressure ulcers have been introduced into patient care and are now in daily use. Classification systems suffer the common problems associated with risk assessment tools. Nurses do not always question them, but have accepted the system they have been given to use, and often do not stop to think whether it has been adequately researched and validated and its reliability confirmed (Walsh and Ford 1989). Classification of pressure ulcers is however essential because it provides a baseline and allows a patient's progress to be monitored. Consequently, classification systems are widely used despite limited evidence to support them. Some Trusts have even chosen to use a particular classification system for no reason other than that local purchaser's use the same one despite the lack of evidence of reliability and validity. Often the purchaser has a limited understanding of how pressure ulcers develop. At least using classification system does provide a baseline to measure outcomes of ones own hospitals progress year on year. The classification system has often been incorporated into pressure sore guidelines without other systems being trialed researched as to effectiveness in the trust. Where classification systems have been imposed without prior education, the information supplied by the staff using the system is often inconsistent. Furthermore the staff may not understand the Pathophysiology underlying how the pressure ulcers develop.

Nurses should be familiar with their adopted classification system in order to make accurate assessment for their record keeping. The ideal method of assessment is to take a photographs (but this facility is not always available), or to trace and manual measurements of a pressure ulcer. It is only by recording this information and evaluating the outcome that the effectiveness of the classification system can be measured. Indeed, inaccurate staging of a wound may have more far reaching effects than the practitioner may realise (Arnold and Walterworth 1995). As patients may develop a very deep pressure ulcer that has not been diagnosed early enough. However, there is no national agreement on a suitable grading system which meets the criteria of reliability and validity, whilst being simple to use. Litigation cases have increased and the grading and documentation of the pressure ulcers provides crucial evidence as to the severity the pressure ulcer (Tingle 1997).

There are many variables to be considered when classifying pressure ulcers. This is far more complicated than it appears, as some nurses' knowledge of different layers of the skin and ability to recognise what stage of healing the wound is at best limited (Young 1996). This concern can only be addressed by a good education programme on the classification of pressure ulcers and wound definitions as a separate issue from other subject areas.

National agreement on the classification of pressure ulcers would have positive benefits, allowing comparison between different clinical environments. Research needs to pinpoint the effectiveness of classification and use of wound care products and pressure relieving mattresses. Once a system has been selected, it is important that appropriate training is given to the users (Fletcher 1995). Documentation presented in a clear and legible format using diagrams and text is helpful. Training should not just occur once but follow up sessions should be organised, e.g. mandatory updates. Classification of pressure ulcers can be monitored by regular evaluation, particularly through link nurses, when prevalence audits are undertaken on a yearly basis.

The aim of using a pressure grading system is to provide a consistent method of skin assessment using a numerical score. This promotes the passage of accurate information between the multidisciplinary team and carers on the patient's progress/deterioration (James 1998). In addition, classification systems can aid in the decision process when considering which pressure-relieving products are to be used (European Pressure Ulcer Advisory Panel 1998). Pressure ulcer grading can reflect the severity of the pressure sore in a number of ways by measuring the depth of the ulcer, the area of the skin affected, and which layers of skin are damaged (James 1998). There are a number of rationales for using classification systems (see table 3.1).

Table 3.1

Rationale for Classification Systems in pressure area care

Advantages :
• To highlight the patients at risk of developing pressure ulcers.
• To enable limited resources to be deployed effectively.
• To be able to devise a plan of care to demonstrate interventions based on the classification of a pressure sore to prevent further skin deterioration.
• To be able to measure patient outcomes.
• A method by which point prevalence and incidence can be measured.
Disadvantages:
• Inaccuracy by different users.
• Complexity of scoring systems.
• Difficulty in assessing the depth of skin damage, e.g. subcutaneous tissues or deeper layers of the skin.
• Approximately 16 different classifications of skin damage exist

Fletcher (1995) states that grading systems should improve diagnosis, treatment, and allocation of resources. Fletcher (1997) states that evaluating pressure sore data is confounded further by the lack of agreement on the grading of pressure ulcers. Grading systems have been developed to help assist nurses with gathering consistent information and defining and describing skin damage with caution (Fletcher 1997).

3.2 Classification of Pressure Ulcers

There are approximately 16 pressure sore Classifications systems which have been published (Healey 1996). An area of conformity on classification scales is that the higher numbers denote the more severe grade of pressure sore. The description of ulcers can contrast from superficial to indurated area of swelling, heat and erythema with superficial breakdown limited to the epidermis (Shea 1975). A particular dilemma is the practitioner not being able to recognise a pressure sore in its early stage and how deep is the tissue damage. Lack of clarity on how to use the grading systems may account for some nurses not being able to detect pressure ulcers in the early stage (Healey 1996 , Reid & Morison 1994). Other variables may also be responsible such as nutrition and body weight.

This chapter now will discuss four classifications systems the Torrance, Stirling, National Pressure Ulcer Advisory Panel and European Pressure Ulcer Advisory Panel systems and their history and reliability and validity.

3.2.1.Torrance (1983)

This classification system has been in common use for the last ten years in some Trusts because it was printed on the back of the Waterlow Scoring card. The Torrance grading system was not tested for its reliability before it was introduced through the launch of Torrance (1983) book "Pressure Scores: aetiology, treatment and prevention". Controversy over the Torrance grading system exists because when does blanching hyperaemia become non-blanching hyperaemia. Some practitioners argue blanching hyperaemia is a normal physiological activity of the body and cannot be substantiated by any time scale (James 1998). The NHS Executive Clinical guidelines state that blanching erthyema should be classed as grade 1. Collier (1999) states that blanching hyperaemia as pronounced erthyema caused by reactive hyperaemia, which still blanches when light finger pressure is applied, indicates the patient's microcirculation is intact. Harker (2000) states that there is general consensus that a grade 1 Torrance is persistent non-blanching erythema. Grade 2 is considered to be non-blanching hyperaemia although epidermal blistering is included in this category. Collier states non-blanching hyperaemia as erythema that does not change in colour when light finger pressure is applied. Hitch (1995) confuses the issue further by stating Torrance grade 2 is presented as superficial ulcer or blisters involving the epidermis or dermis. Torrance does not account for patients who have little or no subcutaneous fat, as some patients are extremely emaciated. Pressure ulcers do not always develop in a set sequence following the Torrance staging. There is also no provision made for patient vasculitic lesions or malignancy (Harker 2000).

The Torrance classification system does not allow for classification of deep full thickness necrotic area (Phillips 1997). Deep bruised, but intake skin is also not accounted for in this classification system.

Table 3.2

The Torrance System (Torrance (1983)

Stage 1	Blanching hyperaemia - Reactive hyperaemia causes a distinct erythema after pressure is released. Light finger pressure will cause blanching of this erythema, indicating that the microcirculation is intact.
Stage 2	Non-blanching hyperaemia - Here the erythema remains when light pressure is applied, indicating a degree of microcirculatory disruption and inflammation. Oedema causes distortion and thickening of all the tissues compressed between bone and the support surface. Superficial damage may present as swelling, induration, blistering or epidermal ulceration which might expose the dermis. If sensory innervation is intact, pain will be present. Friction can cause similar injuries.
Stage 3	Ulceration progresses through the dermis to the junction with subcutaneous tissue. The ulcer edges are distinct but it is surrounded by erythema and induration. At this stage, the damage is still reversible.
Stage 4	The lesion now extends into the subcutaneous fat. Small-vessel thrombosis and infection compound fat necrosis. Underlying muscle is swollen and inflamed and undergoes pathological changes. The relatively avascular deep fascia temporarily impedes downwards progress but promotes lateral extension, causing undermining of the skin. Epidermal thickening creates a distinct ulcer margin but inflammation, fibrosis and retraction distort the deeper areas of the ulcer.

3.2.2.Stirling System (1992)

The Stirling pressure ulcer severity scale aimed to achieve: a classification system that is applicable for use by all nurses. It also attempted classify pressure ulcers using a system applicable to wound care specialists and researchers who require more sophisticated wound description.

It has been agreed for a long time that a National Grading System is necessary. In October 1992 in an attempt to reach an agreement in a consensus conference was held with a panel of fourteen people at Stirling Royal Hospital. The aim of this meeting was to examine the existing systems and identify the practical problems and design an easier grading system. A tool was designed to take into account epidemiology, clinical trial, teaching and patient care settings. There was in depth descriptions of ulcers, skin tone and presence of infarction and gangrene (Reid & Morison 1994). The Stirling scoring system has attempted to overcome this classification problem by addressing factors such as wound bed, presence of infection, but in attempting to do this it has made the scale more complex (James 1998). However, one of the biggest criticisms was that it was not tested for its reliability or validity before its launch and presently still needs to be tested. This was the first attempt at a very difficult task and identified some keys areas that do need to be inherent in any tool devised. Clinical staff do need a common description so that a pressure sore can be measured accurately (Reid & Morison 1994).

Table 3.3

The UK Consensus Classification Of Pressure Sore Severity (Stirling)

Stage 0	
0.0	• No clinical evidence of a pressure sore
0.1	• Normal appearance, intact skin
0.2	• Healed with scarring
	• Tissue damage but not assessed as a pressure sore
Stage 1	
1.1	• Discoloration of intact skin (light finger pressure applied to the site does not alter the discoloration)
	• Non-blanchable erythema with increased local heat
1.2	• Blue/purple/black discoloration. The sore is at least stage 1
Stage 2	• Partial thickness skin loss or damage involving epidermis and/or dermis
2.1	• Blister
2.2	• Abrasion
2.3	• Shallow ulcer, without undermining of adjacent tissue
2.4	• Any of these with underlying blue/purpose/black discoloration or induration. The sore is at least stage 2

Stage 3	Full-thickness skin loss involving damage or necrosis of subcutaneous tissue but not extending to underlying bone, tendon or joint capsule
3.1	• Crater, without undermining of adjacent tissue
3.2	• Crater, with undermining
3.3	• Sinus, the full extent of which is not certain
3.4	• Full-thickness skin loss but wound bed covered with necrotic tissue (hard or leathery black/brown tissue or softer yellow/cream/grey slough) which masks the true extent of tissue damage. The sore is at least stage 3. Until debrided it is not possible to observe whether damage exceeds into muscle or involves damage to bone or supporting structures
Stage 4	Full -thickness skin loss with extensive destruction and tissue necrosis extending to underlying bone, tendon or joint capsule
4.1	• Visible exposure of bone, tendon or capsule
4.2	• Sinus assessed as extending to bone, tendon or capsule
Third-digit classification - for the nature of the wound bed	
x.x0	• Not applicable
x.x1	• Clean, with partial epithelialisation
x.x2	• Clean, with or without granulation, but no obvious epithelialisation
x.x3	• Soft slough, cream/yellow/green in colour
x.x4	• Hard or leathery black/brown necrotic (dead/avascular) tissue
Fourth-digit classification - for Infective complications	
XXX0	• No inflammation surrounding the wound bed
X.XX1	• Inflammation surrounding the wound bed
X.XX2	• Cellulitis bacteriologically confirmed

Reid and Morison (1994)

- The Stirling pressure sore severity scale aimed to achieve:
- A classification system that is applicable for use by all nurses.

An optional extension of the system applicable to wound care specialists and researchers who require more sophisticated wound description.

3.2.3.National Pressure Ulcer Advisory Panel (1989)

This is a classification system nationally agreed in America since 1989 and was the based on previous classifications of Shea (1975) and the International Association for Enterostomal Therapy (1988). The Agency for Health Care Policy and Research (AHCPR) guidelines were based on clinical benefits and harms of potential interventions and relevant health issues . The N P U A P (1989) guidelines state that future studies should use the classification to enable consistent data collection. These guidelines were piloted by Health care agencies using a small number of patients and subsequent modifications made before implementation. On the completion of the guidelines a big conference held by the NPUAP and WOCN and was given federal support for the adoption of these guidelines for patients in acute long term and home care settings.

The guidelines have well designed and research and have been adopted across America.

The European Pressure Ulcer Advisory Panel produced a policy statement on the prevention of pressure ulcers in 1998. Within this statement for maintaining and improving tissue tolerance to pressure in order to prevent injury, recommendations are laid down (table 3.4). This panel chose to adopt the classification that has the format as the NPUAP in America and so this system has been validity and commonly used across America.

The majority of classifications systems have been adopted without large scale trials to compare their effectiveness in clinical practice such as the Torrance and Stirling and this omission needs to be addressed in order provide a classification system that practitioners can use daily, and with consistency and measurable outcomes. National and even European classification is essential for standardisation of patient care.

3.2.4 The European Pressure Ulcer Advisory Panel

The European Pressure Ulcer Advisory Panel produced a policy statement on the prevention of pressure ulcers in 1998 (see figure 3.5). Within this statement for maintaining and improving tissue tolerance to pressure in order to prevent injury, recommendations are laid down. These guidelines give clear directions for:

Table 3.4

European Pressure Ulcer Advisory Panel (1999)

Stage 1	Non-blanchable erythema of intact skin. This may be difficult to identify in darkly pigmented skins.
Stage 2	Partial thickness skin loss involving epidermis and/or dermis. the pressure sore is superficial and presents clinically as an abrasion, blister or shallow crater.
Stage 3	Ulceration progresses through the dermis to the junction with subcutaneous tissue. The ulcer edges are distinct but it is surrounded by erythema and induration. At this stage, the damage is still reversible.
Stage 4	Extensive destruction tissue necrosis, or damage to muscle, bone or supporting structures with or without full thickness skin loss.

- Assessing a patient's skin integrity.
- In an ideal situation, it would be necessary for.
- The classification system to be adopted at a national level [i.e. as the gold standard for nursing patients at risk of pressure ulcers].
- Encouragement from the Tissue Viability Society and the government for assistance with education programmes in order for a National Policy to be adopted.
- Research to investigate whether nurses understand the system and its reliability and validity.

The majority of classifications systems have been adopted without large scale trials to compare their effectiveness in clinical practice and this omission needs to be addressed in order to provide a classification system that practitioners can use daily and with consistency.

3.3. Reliability and Validity

There has been little research into nurses' understanding of the classification of pressures ulcers and this does require investigation as more than half a dozen pressure ulcer grading systems are in common use (Heenan 1994).

Table 3.5

The European Pressure Ulcer Advisory Panel

Recommendations

Skin condition should be documented daily and any changes should be recorded as soon as they are observed.

- Inspection must be documented.
- Initial skin assessment should take into account the following:

  1.Bony prominences (sacrum, heels, hips, ankles, elbows, occiput) to identify early signs of pressure damage;

  2. Identify the condition of the skin - dryness, cracking, erythema, maceration, fragility, heat and induration.

- Every effort should be made to optimise the condition of the patient's skin.
- Assessments of patients with dark or tanned skin are especially difficult.
- Avoid excessive rubbing over bony prominences as this does not prevent pressure damage and may cause additional damage.

- Find the source of excess moisture due to incontinence, perspiration, or wound drainage and eliminate this, where possible. When moisture cannot be controlled, interventions that can assist in preventing skin damage should be used.
- Skin injury due to friction and shear forces should be minimised through correct positioning, transferring and repositioning techniques.

- Following assessment, nutritionally compromised individuals should have a plan of appropriate support and/or supplementation that meets individual needs and is consistent with overall goals of therapy.

- As the patient's condition improves the potential for improving mobility and activity status exists, rehabilitation efforts may be instituted if consistent with the overall goals of therapy. Maintaining activity level, mobility, and range of movement is an appropriate goal for most individuals.

- All interventions and outcomes should be monitored and documented.

Healey's (1995) study observed 109 qualified staff's grading of photographs of pressure ulcers of Caucasian patients. Three grading classification systems were used Stirling digit 1, Torrance and Surrey. The sample consisted of seven trusts in Northeast England. Opinions were sought on the simplicity of use for the individual grading systems. The level of agreement was demonstrated to be :- 67% Surrey, Torrance 60% and the Stirling 39% (when digit 1 was used it rose to 59%). The least complex grading system was preferred by the nurses -Surrey 57%, Torrance 16% and Stirling 11%. The author proclaimed that photographs were not the ideal way to carry out the survey and that real life observations need to be considered for further studies. Also, a larger variety of ulcers would give more reliable data. The grading classifications that were less complex may be more reliable but this was not addressed in this study and further work does need to be undertaken. One reason given by the author was that this might be due to the detail required by the complex classifications that may bewilder the assessor and lead to confusion. There was no agreement on the severity of the grades demonstrated on any of the classification systems.

Buntinx and Becker (1995) conducted a small study on inter-observer variation in assessment of skin ulcers. Three nurses and three physicians, with chronic wound experience, studied twenty-seven skin ulcers using five classification systems to evaluate reliability and validity. Some of the classification systems were very complex and this meant many variables had to be observed. Classification by colour 59% to 93%. The adapted version of Shea's pressure classification gave greater agreement between observers (68%), regarding clinical signs of infection (75%), for inflammation and local heat (76%), and presence of pus (85%). The inter-observer ratings for surface area were comparable. The authors state that a pressure sore classification should not be used when more than one person performs the assessment. Acknowledgement is made that the intra observer reliability were not assessed. Recommendations are made that classifications reliability do need to be investigated for comparability and replication of this type of study.

Montgomery Hunter & Langemo (1995) demonstrated the effectiveness of pressure ulcer prevention and early intervention programme, reducing the prevalence of pressure ulcers in a rehabilitation setting. Forty non-acute rehabilitation patients were recruited from home or from Community Centres. All were over the age of 18 were consented to participate in the prevalence audit over a 16-month period. All patients were assessed on the Braden score, which had been modified for this facility and the threshold that placed the patient at risk was at 18 or lower. All pressure ulcers were assessed using the National Pressure Ulcer Advisory Panel Consensus Statement (1989). Protocols were produced for both prevention and treatment interventions. Education was provided for all current staff on assessment treatment and prevention as were new employees.

The skin assessment tool included a definition of the pressure ulcer, description and staging, and a diagram of all body parts to be assessed. The result demonstrated that a reduction in pressure ulcers from 25% to 10% in a 16-month period was achieved but this sample was not large enough to demonstrate statistical significance. Overall, there was a decrease of 60% in the prevalence of pressure ulcers from the base line of 25%. Patients that did have pressure ulcers had special pressure-reducing cushions and had static overlays or low air loss mattresses at the time of skin assessment. Clearly, good documentation of skin integrity and pressure ulcer risk at the time of being admitted is essential, as is immediate implementation of measures to maintain skin integrity for those identified at risk.

Banks (1998) describes educational sessions that were held in Nursing Homes on classification and documentation of pressure ulcers using the Surrey, Torrance, AHCPR and Stirling grading systems. Each group consisted of four to six people, with at least one qualified nurse who was responsible for assessing the pressure sore damage, Ten minutes was allocated for group discussion on the definition and classification of ulcers. The second activity was to list the reasons for using a particular classification system. The third activity was to identify the potential problems that may arise (table 3.6).

Table 3.6

The potential problems with classification systems

•	Using numerous systems
•	Staff having different levels of experience
•	Assessment of the appearance of tissue damage and its subjectivity from one clinician to another
•	Training difficulties
•	Poor or infrequent documentation
•	Little evidence of reliability
•	No clear rationale for classification of systems used

Adapted from Banks (1998)

The fourth activity encouraged participants to think about pressure sore classification and how it relates to their setting, to compare classification systems and state why they had preference to one system and the limitations of that tool (Surrey, Torrance, Agency for Health Care Policy and Research, and Stirling).

The conclusions do not state what the outcomes of these 4 activities were, but did state that staff who had attended all the first three sessions should have achieved a sound knowledge base on the development and classification of pressures ulcers.

These studies have made an attempt to answer some the problems with classification systems and clearly more investigation is required. Large size trials are required with different grades of nursing staff and consensus panel of experts for the gold standard to compare the answers against from the subjects. The method of assessment of pressure ulcer for research trials is problematically as photographs whilst not the best method are the most practical to maintain a patient's modesty.

There has been very little research into nurses' understanding of the classification of pressures ulcers and this does require investigation as more than half a dozen pressure sore grading systems are in common use (Heenan 1994).

3.4.Problems with Classification Systems

Various systems have been developed to grade pressure ulcers, mainly based on clinical presentation. However, the detection and grading of ulcers, particularly in the early stages, can be quite subjective and unreliable (Cullum et al 1995). This leads to great confusion for the practitioner as to whether the redness is persistent or transient - the latter being described as anything from 30 minutes to 48 hours (Versluysen (1986), International Association of Enterostomal Therapy (1988), Yarkony et al (1990)).

The precise length of time for irreversible tissue damage to occur can vary between individual patients and the support surface, which they have been placed upon. The bright flush of the skin is called reactive hyperaemia and is thought to last between 30 and 45 minutes after the occlusion has occurred. However, if the lymphatic circulation has been irreversibly damaged, the hyperaemia will become non-blanching and blistered. Inflammation may also be present as the small vessels respond to the tissue damage; this will further interfere with the metabolic exchange. Once this damage has been sustained, it is very hard to reverse and may progress to the deeper layers of the skin if pressure is not relieved straight away. "Necrosis does not always begin superficially: it can originate in the muscle and overlying bone" (Barton and Barton 1981). Shearing forces may initially leave overlying epidermis intact, but this will slough off after a few days revealing the damage caused beneath (Bridel 1993).

Grade 1 ulcer are difficult to define and in some classifications systems stage 1 pressure ulcers are described as a reddened area which blanches under light pressure (Dealey (1991), Matlhoko (1994). Alternative grading systems is that a persistent reddened area that does not blanch is a grade 1 (Versluysen 1986), Yarkony et al (1990) Shea (1975).

Lyder (1991) states that blanching erythema would indicate tissue damage had not occurred, then this must precede pressure sore development and thus non-blanching erythema would represent a true presentation of a grade 1 sore. A clear definition, of a grade 1 pressure sore should be as persistent redness for greater than a 24-hour period. High pressure or pressure plus friction can result in the development of pressure ulcers within a 24-hour period (Dinsdale 1974).

Criteria for a grade 1 pressure sore as follows:
• Skin area that ranges from pale pink to bright red in colour
• Skin area that is non-blanching (blanchable erythema being a precursor to a stage 1 pressure sore).
• Skin area that is warmer or cooler to touch
• Skin area with erythema that does not resolve within two hours
• Skin area that possibly has oedema or induration that is ill-defined when palpated
• Skin area with epidermis intact.

Adapted from Lyder (1991)

Hitch (1995) stated that there appears to be consensus on Lyder's criteria for a grade 1 pressure ulcer and this was indicated in the Pressure Ulcers "A key quality indicator" (1993) which provided direction to purchasers and managers in the Health Service. However, no funding was given to help promote as a national classification system.

Dealey (1997) states that even when the concept of a grade 1 sore is clarified, there are still some problematic areas in grading pressure ulcers to resolve. For instance, if a pressure sore is covered by black necrotic tissue, full clinical assessment of the wound will not be possible until the necrotic tissue has been debrided.

3.4.1 Superficial and Deep Pressure Ulcers

Bliss (1988) stated that superficial ulcers occur principally in dehydrated or incontinent patients. Superficial pressure ulcers are often overlooked but they can cause great distress to the patient. The pressure ulcer may be exacerbated by intrinsic factors age, collagen content of the skin, nutrition and unrelieved pressure other extrinsic factors such as friction, shear, incontinence and skin irritants and these factors require careful assessment and management otherwise the superficial ulcer will take longer to heal.

Lowthian (1987) suggests that skin damage should be included on the small ulcers to prevent scratches and pustules being graded as pressure ulcers. Skin diseases should be clinically diagnosed by a dermatologist. Girvin and Griffin Jones (1989) demonstrated a higher prevalence of grade 2 pressure ulcers over grade 1. This study implies that grade 1 pressure ulcers were not being identified, implying that early detection and prevention was not occurring (Hitch 1995).

Young (1996) states there are many classification systems and there appears to be a consensus in grade 4 and 5 ulcers, but not in the initial stages of skin damage. A stage 4 sore would involve the presence of the subcutaneous layer and an obvious cavity with possible necrosis. In stage 5 ulcers, whereby muscle and bone are exposed, necrotic tissue or infection will be present. Stage 3 ulcers are a break in the dermis and possibly involve the subcutaneous tissue. Hitch (1995) states there appears to be a consensus of opinion is that grade 2 pressure ulcers present a superficial ulcer or blistering, which involve the epidermis or dermis.

Deep pressure ulcers can spread down to the bone and but the pain that they cause frequently inhibits movement, resulting in further necrosis. Black eschar occurs when the blood supply is pressed against underlying bone (Witkowsky and Parish 1982). It's dry nature of the black eschar suggest that necrosis occurred without perfusion of the skin. This area requires further research.

The surface size and severity of the ulcer needs to be evaluated, due to the varying depths of anatomical layers within the individual and within different areas of the body that are not covered in any ulcers (Lowthian (1987), Reid and Morison (1994)). Different sites on the body have thinner layers of tissue, in particular the heels, buttocks and trochanter (Reid and Morison 1994). This is an area that has not been investigated at all and does need to be considered when classifying the grade of a pressure sore, particularly on a heel where the grade of sore can progress very quickly from a 3 to a 5 within a short space of time. Early detection of a change in skin condition takes extensive skill and clinical judgement and training, e.g. nurse specialists.

3.4.2.Intact skin

Further complication occurs with grading on intact skin, but there may be evidence of tissue necrosis, which can be fully examined (Hitch (1995), Dealey (1997)). In this event, some clinicians grade the sore at its worst severity, e.g. a grade 4. Infection of a pressure sore has not been widely covered in classification. Torrance assumes all grade 4's are complicated by infected necrosis. Sacral pressure ulcers are more predisposed to infection containing a mixture of aerobic and anaerobic micro-organisms derived from the bowel (Grey 1998). The majority of deep pressure ulcers demonstrate the development of cellulitis around the sore and this only decreases once the pressure sore starts to heal. It is only when necrotic tissue has been removed that full assessment can occur of all the tissue damage sustained (James 1998).

Nurses are exposed to a wide variety of classifications of pressure ulcers, e.g. a patient with unbroken skin but a purple sacrum with ischaemic tissue could be identified as a grade 1 sore in the Surrey and Lowthian classifications but as grade 2 in the Torrance system. Grading of superficial pressure ulcers, such as Torrance and Shea, makes no allowance for potential damage that could have occurred beneath the skin. In this case the patient is likely to have a full thickness pressure sore involving the muscle fascia and possibly bone within a few days.

3.5 Definition of Reactive Hyperaemia

Bliss (1998) defines hyperaemia as the process by which the body adjusts blood flow to meet the metabolic requirements of the body both in health and illness.

3.5.1 Reactive Hyperaemia

Lewis & Grant in (1935) demonstrated that occluded blood flow to the arm by means of a tourniquet, which was tightened and then released, showed that the blood vessels were already dilated before the pressure was relieved. In addition, the degree and the duration of increased flow was proportional to the period of occlusion. Thus, a short occlusion of 5 seconds was sufficient to cause reactive hyperaemia. Occlusion over 5 minutes caused plateauing of the hyperaemic response (Michel and Gillott (1990). The ischaemic results in damage to the cells release inflammatory agents such as histamine.

Reactive hyperaemia, when occurs when oxygen debt occurs due to occluded blood supply and accumulation of waste products. The micro circulation is controlled by the sympathetic vasoconstrictor messages from the brain to area of local tissue where pressure is being applied (Bliss 1998). The local endoththelial cells and other tissues produce chemical and hormones. These hormones, adrenalin, noradrenalin and vasopressin cause vasconstriction and recently vaso-relaxants, nitric oxide (Petty and Pearson (1989), Vallance and Moncada (1994), Joyner and Deitz (1997)). Nitric oxide has shown to have vital role in promoting normal blood flow throughout the body.

3.5 2 Hyperaemic Response to Trauma

The hyperaemic response may occur in three ways (Lee and Thoden 1985):

- 'Whiteness' due to forcing blood out of the venous plexus;
- 'Flare' partly due to an axon reflex which causes vasodilatation in the surrounding veins, venules and capillaries, and party due to the release of cytokines such as histamine, bradykinin and serotonin by the damaged cells;
- 'Wheal' is oedema caused by increased capillary permeability due to the cytokines.

The above responses seldom last for more than half an hour and reactive hyperaemia is even shorter, usually only a few minutes. Hence the affected area may be superficial or deep within the body.

3.5.3 Blanching Hyperaemia

Reactive hyperaemia causes a distinct erythema after pressure is released. Light finger pressure will cause blanching of this erythema, indicating that the microcirculation is intact (Torrance 1983, Collier 1999). This tissue damage is usually superficial and transient whilst the blood flow is occluded. The structures involved are the arterioles capillaries, epidermis and dermis. In the Torrance grading system a grade 1 pressure sore if acted on promptly the tissue damage can be reversed very easily.

3.5.4 Non-blanching Hyperaemia

When light finger pressure is applied erythema remains indicating some degree of micro-circulatory disruption often associated with other clinical signs, blistering, induration and oedema (Torrance 1983). The deep structures such as muscle are involved in this level tissue damage (Collier 1999). Hitch (1995) suggests that persistent erythema over 30-40 hours will take longer to treat as opposed to 2 hours which can be resolved quickly by prompt treatment.

3.5.5 Erythema

There may be number of causes to erythema for instance wound infection or damage through a burn or scald and usually the patients temperature would be raised . Erythema could be defined as non-specific redness of the skin, which can either be localised or general in nature, which may be associated with cellulitis (Grey 1998), infection, prolonged pressure or reactive hyperaemia. Persistent erythema which lasts for longer than half an hour is almost always a sign of substantial trauma or infection. It is caused by inflammation due to the continuing release of cytokines by dead cells (e.g., due to a pressure injury) and/or bacterial products which cause prolonged vasodilatation and increased capillary permeability (Bliss 1998). This allows the escape of fluid and protein, mainly fibrinogen, and inflammatory cells, leukocytes and monocytes, into the interstitium (Guyton 1981). The erythema due to vasodilatation persists for as long as necessary for the tissues to isolate the dead cells and/or bacteria by fibrinogen clotting in the interstitium and lymphatics, and for them to be engulfed by leukocytes and macrophages (either resident in the tissues or matured monocytes) (Guyton 1981). Oedema and pain will accompany the redness.

3.5.6 Temperature

Temperature has also been associated with the hyperaemic response - the higher the temperature, the faster the response. Less tissue damage occurs if the temperature is lowered during the occlusion. The metabolic rate also decreases along with the requirements for oxygen and nutrients. There is a build up of waste products (elevating the temperature by 1° causes 13% increases in metabolic demand (Bogie *et al* 1992)).

3.6 Wound Classification or Pressure Classification

Classifying pressure ulcers according to colour alone is inadequate (Benbow 1995). Young (1996) and James (1998) state that colour classification can result in confusion other conditions - in particular pyoderma gangrenosum could be mistaken as it presents itself initially as a black skin lesion and then progresses to a reddened area. Other conditions that could be confusing are osteomyelitis of the hip as this may produce a hot inflamed reddened area on the trochanter, which could be interpreted as a non-blanching erythema. "The inaccurate staging of wounds may have more far reaching effects than some practitioners realise" (Arnold & Watterworth 1995).

Systems of systems have been designed for pressure ulcers but some practitioners use them to stage wounds with different pathology (Young 1996). However, pressure ulcers do not always progress through the classification stage, so this creates difficulty when trying to document wounds in this fashion. Bergerstrom et al (1995) state that pressure ulcers do not necessarily progress from a stage 1 to a stage 4 or heal from a stage 4 to a stage 1. Pressure ulcers classification systems were never designed to be employed as a method of describing improvement in a pressure sore (Wright 1997). Wounds are better classified as superficial, partial or full thickness and pressure ulcers graded separately (Young 1996). Colour classification is still relevant in both wound and pressure sore grading systems.

Wright (1997) designed a Skin Care Evaluation sheet for assessment and on going weekly assessment for long term care facilities to clarify any disputes that occur on the cost patients treatment. Patient wounds were assessed as the "*original stage*" and the weekly reassessment the "*greatest stage* being *visualised stage*". The form documents wound type, size, depth, stage, drainage, odour, colour, inflammation and treatment and wound swab taken. Photographs were also taken on monthly basis until re-epithelialised. This tool has not been validated or tested for its reliability between different nurses.

3.6.1 Blistering of Skin

Blistering of the skin can confuse the degree of tissue damage as there may be fluid in the blister, which will obscure the degree of skin integrity. Some clinicians grade ulcers at their severest and this does not always accord up with the classification they may have used.

3.6.2 Skin Tone

Darkly pigmented skin creates problems as early skin changes are not evident Meeham (1994) demonstrated that patients with dark skin had a larger percentage of high grade ulcers and the least number of stage 1 ulcers. The practitioner needs to be aware of this type of patient so that early detection, such as boggy heels which often indicates early tissue damage, are acted on promptly to prevent any further skin deterioration.

Heels deteriorate really quickly and particularly if the early skin changes occur in Caucasian skin alerting the practitioner to take prompt action.

Skin pigmentation can create problems in recognition of erythema and the extent of damage (Fletcher 1995) and palpitation of the skin is more useful in these circumstances (Young 1996). Observation of localised heat should also be taken into account.

The National Pressure Ulcer Advisory Panel set up working party (Henderson, Ayello, *et al* 1997) to review the literature on stage 1 pressure ulcers in darkly pigment skin. The literature was sparse and no scientifically bases papers were available. Concerns have been raised on the difficult practitioners have in defining darkly pigmented skin (Graves 1990, Barr 1993, Eltorai 1994, Cardwell, Popence 1995, Lyder 1996, Maklebust, Sieggreen 1996). Meehan (1994), Barczak (1997) demonstrated that African – Americans had more full thickness pressure ulcers than superficial ulcers. Superficial ulcers went undetected with patient with darkly pigmented skin. The NPUAP approved revised definition of stage 1 pressure sore:

"An observable pressure related alteration of intact skin whose indicators as compared to adjacent or opposite area on the body may change in skin colour (red, blue, purple tones), skin temperature (warmth or coolness), skin stiffness, and / or sensation (pain)".

This definition is still revised and will be available in the near future. Outcome measures for stage 1 ulcers cannot become a reality until there is a clear inclusive definition with predictive validity that can be used in research and clinical practice (Henderson, Ayello, *et al* 1997).

Patients' quality of life does significantly suffer with a pressure ulcer because the number of dressings required for a deep pressure ulcer will increase. The smell of the exudate also may be an embarrassment to the patient. The pain and the distress the patient will experience will not easily be forgotten - even after the pressure ulcer has healed.

3.7 Conclusion

The classification of pressure is very complex in particular the first stage of a pressure ulcer is very difficult to define. The four stages of hyperaemia make it confusing for the practitioner, whose comprehension of the aetiology of pressure ulcers becomes clouded (Collier 1999). There appears to be consensus on the grade 3 and above ulcers because the aetiology of these pressure ulcers is clearly defined. Accurate identification of all these stages needs to be understood fully in order to enable pressure ulcers to be prevented or treated early enough. New methods of defining an early stage of pressure ulcer does need to be discovered and could have great economic benefit to the Health service and ultimately the patient and pain and discomfort pressure ulcer cause. Very little research exists on ethic skin tone and how to prevent the deep ulcer that occur due to the early development of a pressure going undetected. Agreement on a national or European classification of pressure ulcer is urgently required with adequate research to ascertain it reliability and validity.

Chapter 4

Image Analysis

Chapter 4

Image Analysis

4.1 History of Image Processing

The fundamental foundation of image processing occurred in the 1960s. In the United States the National Aeronautic and Space Administration (NASA) produced technology to support the lunar science programme. NASA wanted to explore the lunar surface of the moon and developed the Ranger Programme. The Ranger Programme relayed pictures of the lunar surface, elevation and composition to enable maps of the moon to be drawn up (Baxes 1994). The Ranger images were created and relayed to Earth by an analogue signal. This was then converted into a digital form and then processed digitally by NASA at the Jet Propulsion Laboratories and then corrected by various camera diametric and distorted successfully. The computers that were used for these processes were main frame computers and extremely large and bulky (Baxes 1994). The images from Ranger were essential for the inter Apollo missions.

The most recent NASA exploration programme that obtained spectacular results using digital imaging is the Hubble Space Telescope. The main mirror of the space telescope was incorrectly machined due to incorrect placement of spacers in the mirror grinding mechanism. This resulted in failure of correct focusing. Initially, it was thought to be a unsolveable disaster but computer image manipulation allowed useful images to be collected. Later, a specific mechanical box (extra mirror to rectify the focus error was installed. The success of these missions have been judged by the quality of images returned to earth (Russ 1998).

Through NASA's exploration of the technology, other applications have been developed. In the 1960's medical diagnostic imaging and digital imaging of x-rays was developed. In the 1980's these expanded to digital techniques and involved Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET) and finally ultrasound. The applications of image processing are now numerous. Satellites now provide military surveillance, weather and television broadcasts. Biological research, image enhancement, DNA typing, document processing, scanning and archiving and bank statements and tax forms all involve image processing. One of the major uses is factory automation, which took over from human quality inspection. Forensic examination of fingerprints and DNA matching is also a common use for image processing. Laboratories use digital image processing to check for impurities and grain size. Breweries test alcohol content by bubble size analysis. Photographers may use digital techniques to enhance images, e.g. sharpening, contrasting, colour balancing or even un-blackening of a single tooth. The publishing world now uses desktop publishing widely for the layout of image text and graphics detail and colour separation into cyan, magneta, yellow and black films. Film production also employs various digital image processing techniques, adding for printing subjects to scenes, synthetic imagery and special effects. Another common forms of image processing involves television programmes that can now be transmitted using cable or satellite use digital transmission and compression. Video machines can archive these transmissions and reduce the size of information, making archiving faster, efficient and more cost effective.

In order to understand image processing it is essential to comprehend how the human visual system works and the limitation of the eye and the brain (Baxes 1994).

4.2 Image processing

"Image processing is defined as 'manipulation and analysis of pictorial information'. Usually pictorial data is two-dimensional visual images. The operation to analyse and correct this picture is called 'image processing' (Baxes 1994)".

We therefore possess one of the most phenomenal image processing units – the human eye and the brain. Information is assimilated through the eye when we focus, acquire, enhance, restore, analyse, compress and store the image in our brain. This can be undertaken at a phenomenal rate and sometimes without consciously being aware of it. The most common form of manmade image processing is the prescription eyeglass. Eyeglasses use geometric pre-distortion to alter the image landing on the wear's lens so that the image on the retina is perceived correctly. The television receiver is also a form of image processing. The controls allow adjustment of brightness, contrast, tint and colour to your own preference. This mode of control alters the interpretation colour of the electrical pulse signals received and processed from the transmitted signal and the Hue and saturation modified picture is displayed on the television. Other forms of distortion perception are a mirror in a fair ground that make you appear smaller or larger than you really are.

There are three main methods of image processing.

4.2.1 Optical Imaging

One type of optical imaging is the change of light to an electrical signal e.g. a video camera. The converted image is a form of "electrical light" that continuously varies electrical impulses. Another example of an optical image process is a photographic camera in a dark room. Photographers are able to enhance and manipulate a picture using sharpening, filtering etc. to give an aesthetic picture (Baxes 1994).

4.2 2 Analogue Image Processing

Usually this is an electrical circuit to carry out a simple operation. Television receivers use analogue image processing techniques: in a black and white television, voltage levels are arranged to represent the brightness throughout the image that is transmitted. If the user changes the brightness and the contrast the television picture will adapt to the overall voltage and aptitude. The black-level will offset the video signal changing the displayed picture (Baxes 1994). A colour television works similarly using 3 electron guns (red, green and blue).

4.2.3 Digital Image Processing

With the advent of digital circuits, computer processors and software has opened a far more accurate way of image processing with flexibility. Some of it can be adapted for use in different processing applications. The digital image comprises numerical points of brightness. The alteration of brightness values, which is very complex, can easily be accommodated by today's digital computers. Digital image processing allows research to be undertaken to meet the increasing pace of commercial demand and technology and this is an ever-expanding industry (Baxes 1994).

4.3 The Eye

The eye acts in the same way as a camera, but there are fundamental differences between human vision and imaging devices. Human vision is primarily qualitative and comparative rather than quantitative (Russ 1998). The first part of the eye to receive light is the cornea, which is a convex lens, refracting the rays of light in the first focusing stage of vision. The cornea provides a tough protective outer covering for the transparent tissue that covers the anterior surface of the eye (Gonzalez & Woods 1993). The light then travels through the aqueous humour, through the iris and then lens. The iris controls the amount of light that enters by contracting and dilating. The lens carries out the final focus by projecting light onto the retina. The muscles around the lens adjust the focal length of the optical system, depending on the distance the object is being viewed from. The light then travels through a second fluid, the vitreous humour, which helps maintain the structure of the eye whilst optically matching the lens to the retina. The retina acts as the light detector that converts the intensity and colour of light into signals that can be sent to the brain. The detector system has some 100,000,000 photosensitive cells these relay the information to the brain via nerve impulses (Baxes 1994).

There are two types of photoreceptor cells, rods and cones. Approximately 1,000,000 are rods, which respond to light across a broad spectrum of the colour of light, but are unable to separate, out the different colours. The rod tends to be used for low light vision and night vision. The cones of which – there are 6,000,000- 7,000,000 are mainly used for bright light and spectral bands of colour light (Gonzalez & Woods 1993, Baxes 1994).This allows discrimination through a system of trichromacy.

Rods and cones are distributed across the retina. Cones are numerous around the location of the fovea. Hardly any rods or cones are found around the area called the blind spot where the optical nerve leaves the retina (Gonzalez & Woods 1993). This allocation of rods and cones across the retina enable colour censoring and perception, and the eye is best directed at a forward vision. Colour vision is predominately central giving the peripheral vision no nominal colour perception. When light strikes the rods and cones an electrical chemical response generates a nerve impulse to the brain via the optical nerve. The area of the brain where the impulses are processed is the visual cortex.

Before information is assimilated in the visual cortex, some intensity analysis occurs in the eye itself. These phenomena can affect the way we use a digital image processing technique to improve an image to the human observer. The relationship between the intensity of light entering the eye and the perceived brightness is not a linear function (Baxes 1994). When the intensity of an object being viewed is changed, the viewer will not perceive an equal change in the brightness. The eye actually measures intensity in a logarithmic scale which measures linear increase in signal output from the eye corresponding to an upwardly curving signal input. Thus, changes in intensity in dark regions tend to be picked up easier than changes in bright light areas. A limitation of the eye is the linear resolution. Since the photosensitive units have finite width, there are difficulties in separating some features e.g. strips. This is also complicated by a second phenomenon. The second phenomenon is caused by lateral inhibition "Mach band" effect. The eye has the ability to accentuate sharp intensity changes. It adds apparent brightness and under shoots or over shoots to its response (Gonzalez & Woods 1993, Baxes 1994). An example of this is that the intensity of stripes that are constant are perceived as a brightness pattern that is strongly scalloped in particular at the edges. This is known as the "Mach band " first described by Ernest Mach in 1864.

When the concepts discussed above (non-linear intensity response, photoreceptors interactions and frequency sensitivity of the eye) are combined together of the some generalisations can be made.

1. The intensity of an object is related to the average intensity surrounding the object. The object appears darker if the surrounding area is brighter or brighter if the surrounding area is darker.

2. Subtle intensity changes are more apparent in dark regions than in bright regions of an image.

3. Sharp intensity transitions within an image are accentuated.

4. The response to image detail falls off as details get too fine to resolve. Details with high contrast are more resolvable than these with the low contrast (Baxes 1994).

The digital image processing system optimises these operations by the human eye and brain to produce an image that is optimised for the human observer.

Russ (1998) states that humans are especially poor at judging colour and brightness of features within images unless they can be compared exactly by making them adjacent. However, gradual brightness changes can be accommodated in the human eye and compensated for automatically.

4.4 History of Colour

The fundamentals of colour were discovered by Sir Isaac Newton in 1666. He noted that when sunlight passed through a glass prism the emerging beam of light is not white, but a continuous spectrum of colour consisting of violet, blue, green, yellow, orange and red and these colours blend smoothly into each other. The colours that a human perceives in an object are determined by the nature of the light reflected from that object. Light consists of a relatively narrow band of frequencies of electro magnetic energy spectrum (figure 4.1). For example x-rays occur at 300 nanometres (nm), whereas microwaves occur at 600 nm. A surface that naturally reflects light that is relatively balanced in all visual wave lengths appears white to the observer. Any surface that favours reflectance in a limited range the of visual spectrum exhibits some shades of colour e.g. green objects reflect light at approximately 550 nm wavelength and absorb most of the energy from the other wavelengths (Gonzalez & Woods 1993).

One of the characteristics of colour is that it is dependant upon light. Light is achromatic (void of colour). Its only attribute is its intensity, or amount. When viewing a television set in black and white achromatic light is seen by the viewer. The grey level refers to the scalar measure of intensity that ranges from blacks to greys and finally to white.

Electro magnetic energy spectrum chromatic light occurs at approximately 400-700 nm and consists of 3 components radiance, luminance and brightness. *Radiance* is the total amount of energy that flows from a light source and is measured in watts (w). *Luminance* is the amount of energy an observer perceives from the light source e.g. light emitted from a source operating in the infra red region could have significant radiance. To the observer the luminance would be zero. *Brightness* is very subjective and may vary on how the observer views it and is very difficult to measure (Gonzalez & Woods 1993). The brightness refers to the measure of intensity after it has been captured by the camera, sampled, quantified, displayed and observed by our eyes (Baxes 1994).

Although colour is a continuous variable, the human eye sees colour as variable combinations of the three primary colours red (R), green (G) and blue (B). In 1931, the International Commission on lumination designated specific wave lengths values to the three primary colours in order to give a standardised approach. Blue – 434.8 nm, green 506.1 nm and red 700 nm. These three colours (RGB) can act independently and generate all colours (see Figure 4.1). The addition of light does contribute to the colour that is produced and the intensity that is produced (Gonzalez & Woods 1993).

Primary colours become secondary colours when light is added to become:

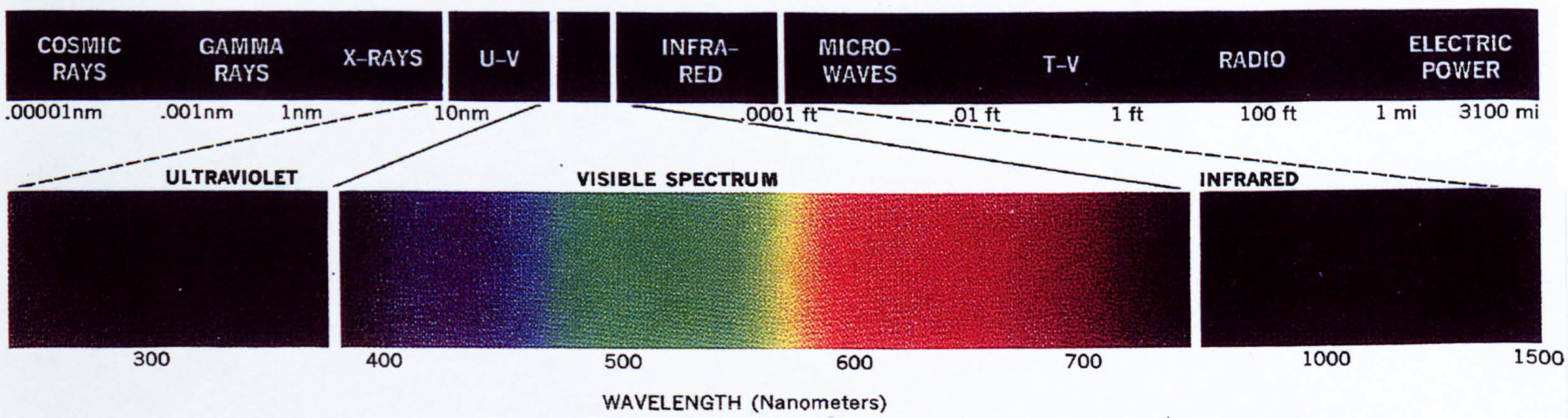
Secondary Colours of light	
Magenta (Primary colour pigment)	= red + blue.
Cyan (Primary colour pigment)	= green + blue
Yellow (Primary colour pigment)	= red + green.

When a primary, or secondary colour is combined with its opposite primary colour in the right intensities white light is produced.

A colour television tube is a prime example of the additive nature of light colours. The colour tv tube is comprised of a large number of triangular dot patterns of electron sensitive phosphor. When excited each dot in the triad is capable of producing light in one of the primary colours. The intensity of the red emitting phosphor dots is regulated by an electron gun inside the tube which creates waves corresponding to red energy seen by the tv camera. The green and blue phosphor dots responding in the same way as the red does. These combine together and are received by colour sensitive cones in the eye and a full colour image is perceived by the viewer (Gonzalez & Woods 1993).

Figure 4.1

Wavelengths in nanometres



Adapted from Courtesy of General Electric Co. Lamp Business Division

4.4 1 Characteristics of Colour

A characteristic that helps us distinguish one colour from another is brightness, hue and saturation. Brightness includes the chromatic theory of intensity (e.g. gray scale). Hue is associates with the wavelength in a mixture of light waves. Thus the hue represents the dominant colour viewed by the observer e.g. when we call an object red, orange or yellow we are specifying its hue. Saturation represents the relative purity or the amount of white light mixed with a hue (Baxes 1994). The pure spectrum colours are fully saturated. The less saturated colours are pink (red and white), lavender (violet and white). The degree of saturation is proportional to the amount of white light added. When hue and saturation are combined the term described is the colour chromaticity. Therefore, a colour may be characterised either by its brightness and hue or its chromaticity (see figure 4.2). The amount of red, green and blue needed to form any particular colour are called tristimulus values and are denoted, X, Y and Z respectively. A colour is then specified by its trichromatic coefficients (Gonzalez & Woods 1993).

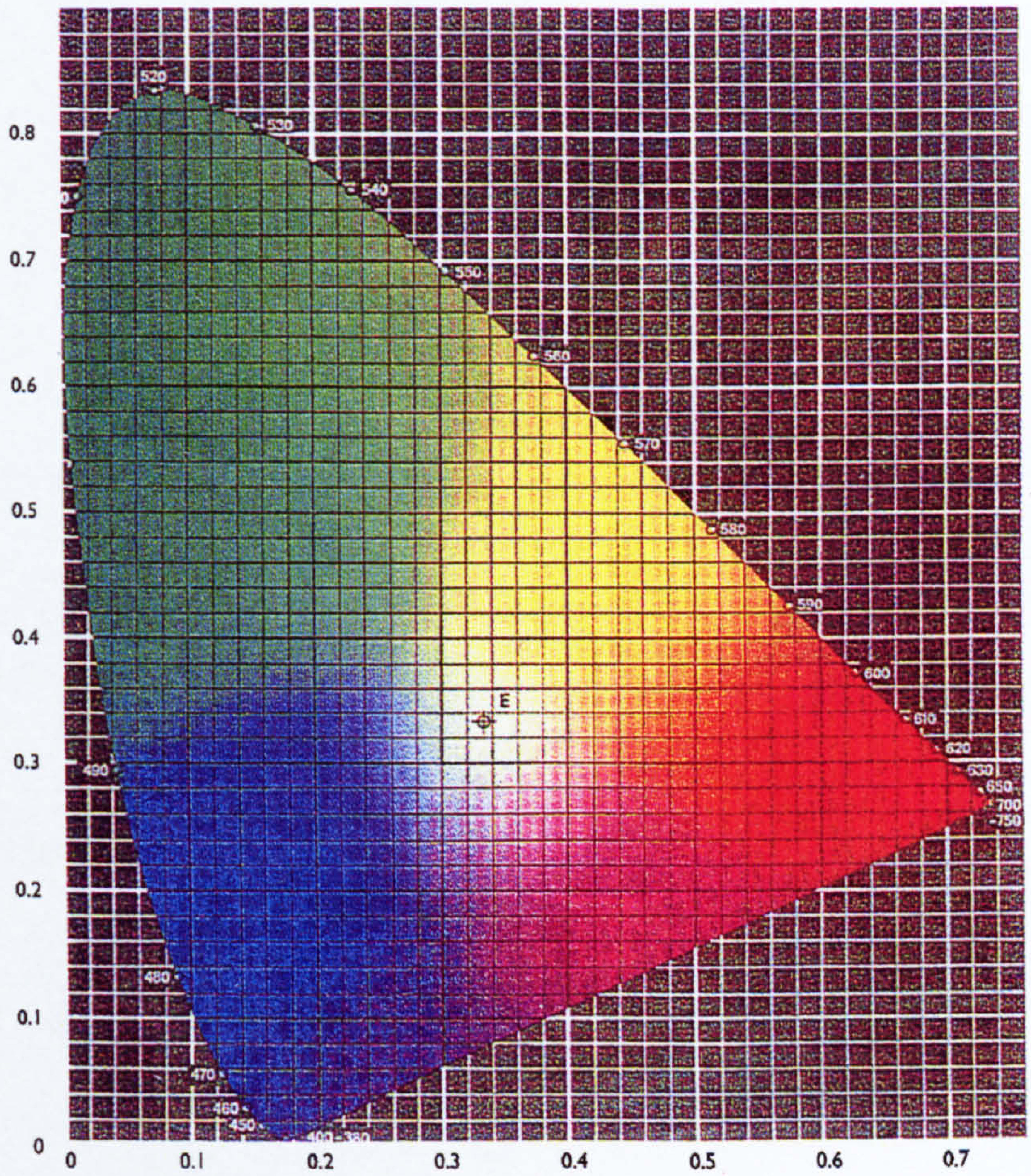
4.5 Colour Models

These are three main colour models, which allow particular features of 3 D co-ordinate systems and sub space to be used to describe colours. Within these systems, colours have set places at a single point (see figure 4.3).

Figure 4.2

Chromaticity diagram

Showing the relationship between at outer edges, saturation of white light from centre outer edges for each hue, and intensity from white to black.



Adapted from Boardman et al 1994

The most commonly used models of colour image orchestration are Hue ,Saturation and Intensity (HSI) and Hue Saturation and Value (HSV) as used by Every day hardware that employs colour manipulation, e.g. printers for computers, and colour graphics. The most universal colour model is Red, Green, Blue, (RGB) and is found in colour monitors in televisions, video cameras (Gonzalez & Woods 1993).

4.5.1.The RGB Model

This model is based on the primary colours red, green & blue and uses the Cartesian co ordinate system: The subspace colour is divided into three corners, the origins are black and travel through to white and mid point is gray scale. The colour points are all inside the cube matrix, which extends from the origin. An assumption is made that all colours have been customised so that so that cube shown in (figure 4.3), demonstrates RGB individual values. When the three primary colours combine in a colour monitor on phosphor screen a consolidated colour image appears (Gonzalez & Woods 1993).

One problem with the RGB model for image analysis is that when enhancing a colour image of a human face that is part hidden in shadow, the flesh colour tone will not appear very natural, after enhancement.

4.5.2 HSI Model

The principal HSI model is based upon Hue: colour being described as pure yellow, orange or red. Saturation gives a measure of the degree to which a pure colour is diluted by white light (see figure 4.4). The intensity component is combined with colour information to form a colour picture. Hue and saturation components are intimately related to the way the eye perceives or receives colour. This unique feature makes the HSI model an ideal tool for image processing as it uses algorithms based on human visual perception (Gonzalez & Woods 1993). HSI is used particularly in automated tests, for instance the ripeness of fruit and vegetables based on matching colour and quality.

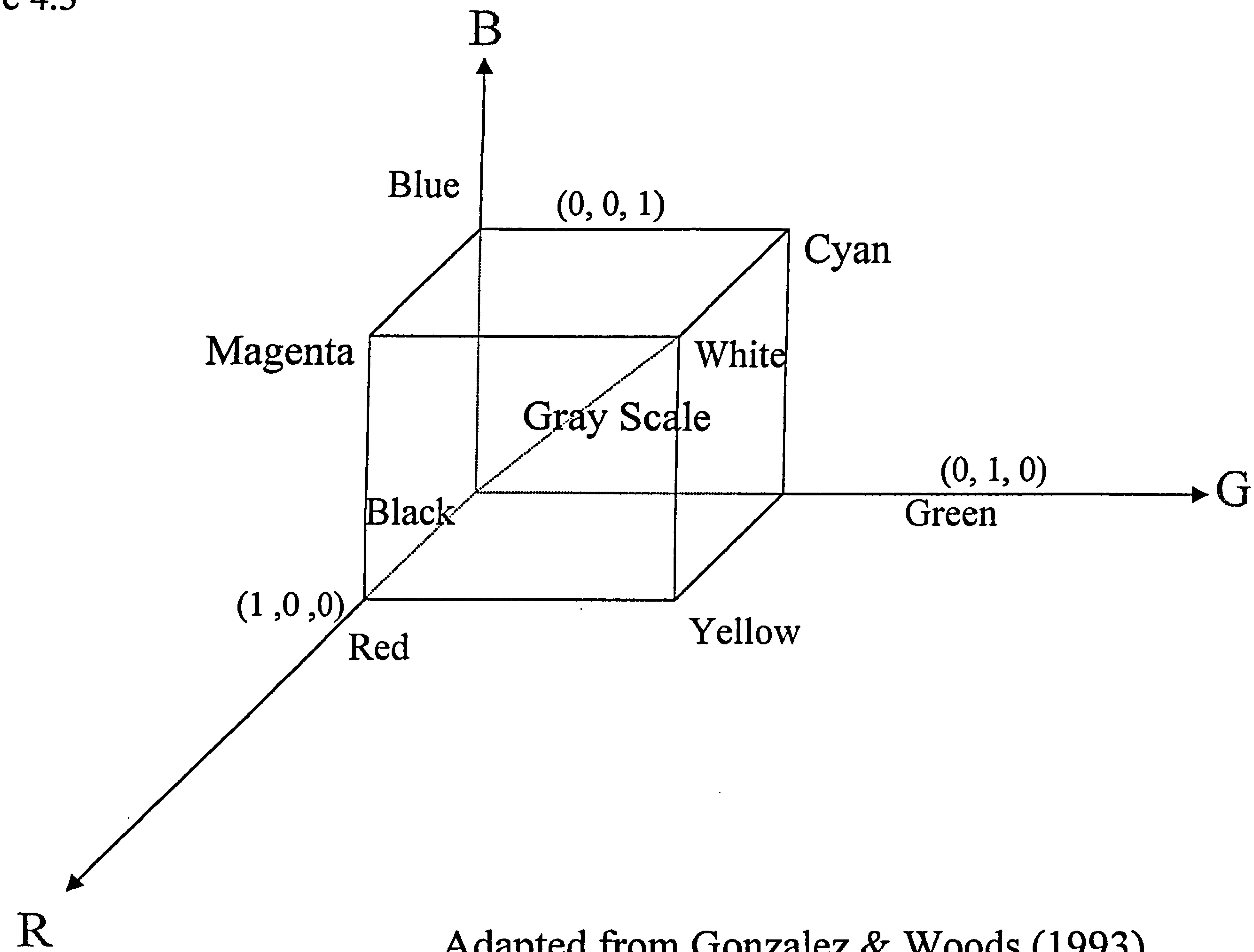
4.5.3 Digital Image Processing System

The digital image processing system comprises of hardware and software components that acquire, store, display and process digital images, the image captured is important e.g. video camera, although most of these systems operate independently (Baxes 1994).

The camera receives analogue data and digitises it to become the stored record. Digitalisation is carried by fast semi conduction device. To produce a picture that can be displayed on a monitor or a computer, the digital image data is reconstructed back to an analogue signal.

Figure 4.3

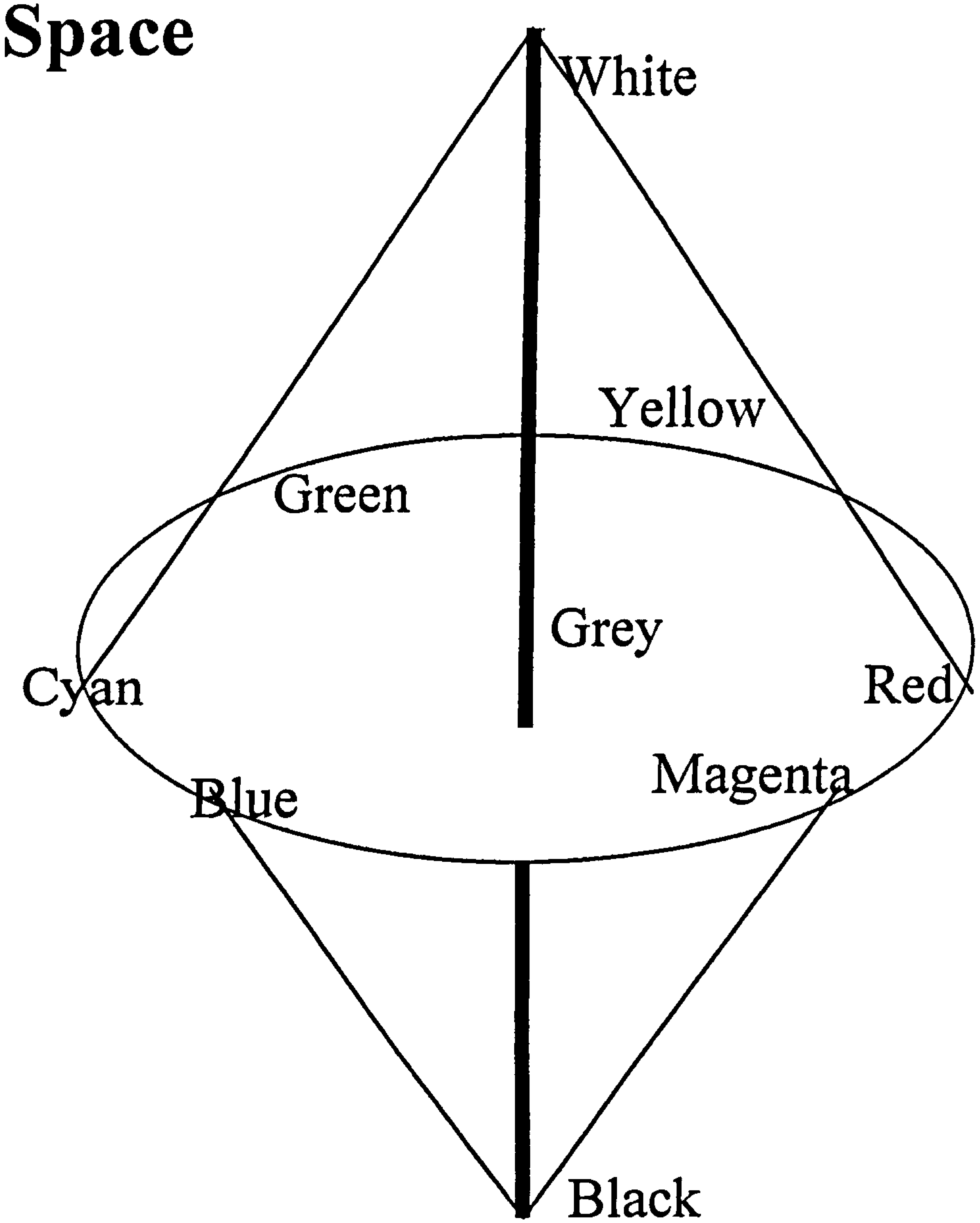
RGB Colour Cube



Adapted from Gonzalez & Woods (1993)

Figure 4.4

Bi -conic representation of Hue-Saturation and Intensity in Space



Adapted from Russ (1999)

4 6 Photography

Digital picture quality is not as high as that of film (Melhuish 1997). However, there are also problems with film, which are relevant for clinical trials. In this a Kodak 410 digital camera system was used to capture images. The advantages of digital images are: -

1. No film was involved, so therefore no data could be lost in the post while being sent for development.
2. To analyse a film images/ would require scanning. This is was eliminated by recording directly to digital.
3. It would be impossible to keep the same batch film throughout the eighteen months of the study. Variation in the processing of film is monitored closely for quality, but each film will be different and the chemicals involved may vary subtly affecting HSI values in resultant prints.

4.6 1 Lens

Type of lens has to be considered in photography and whether it is a manual or automatic focus. Automatic focus can be useful for close up work (Melhuish 1997). The size of items at different distances within photographs taken with a 44 mm lens are less at variance with normal vision. A wide-angle lens (28 mm) provides greater depth of field, but may distort the subject by exaggerating the central field of focus

(Hedgecoe 1979). Zoom lenses are popular as they allow for variable focal length within the same lens, when the angle of view may not be identical in each case.

4.6 2 Lighting and Flash

At f-4.6 at 10 inches with a flash gave the clearest and most realistic photographs, whereas a synchronised electronic flash facing forward tends to flatten the subjects, bouncing flash at 14 degrees above the subject helps to resolve the problem (Louis 1992).

It is important to consider lighting conditions in a room where the images are being taken. For instance, a patient's image taken at a bedside may only produce a dark photographs with gray tones, giving the skin tones a muddy appearance (Louis 1992). The ideal is to use additional lighting in a studio with the same lighting conditions for every image. However, extra lighting at a patient's bedside is very impractical to carry out as it is time consuming and cumbersome. An electronic flash is recommended as the light in most hospitals and community areas will be inadequate (Melhuish 1997). A flash dedicated to the camera body is preferable. It may be advisable to use a ring flash if possible for close ups (Melhuish 1997). Cameras with a built in flash or with a detected flash that is attached to the camera may be the best. We found this to be more appropriate for consistent method. The position of the flash is also important and sited about the lens allows better illumination of the subject (Melhuish 1997).

Ensure that the flash exposes the patient's area of interest and not the background. It is essential to also keep background constant and uncluttered (Melhuish 1997). Mid grey is the best type of background but not is very easy to get hold of (Belam 1999). Usually in hospital white sheets are used.

4.6.3 Image Capture

The 'E' and 'F' stops of a camera also needs to be considered for consistency Louis (1992) experimented with a Nikon 44 mm f 4.61/60 with a shoemount flash and images taken at different distances 10, 20, inches away from the pressure sores. It appeared at first glance that the image 10 inches was larger. One way of differentiating was the tape measure involved in each photograph which gives an impression of how near or far the photographer is away from the patient.

Images taken for clinical trials should always be taken consistently and with a scale for measurements as well as the trial number for patient identification. Louis (1992) stated that measuring tape should be cut to fit along the patient's skin in the length and breadth of the wound. However, this creates difficulties as sacral pressure sores are usually on a curved part of the body, making it difficult for calibration of measurements. This may be overcome by placing the measuring scale on a narrow right angled card which this can be placed along side the wound that is being photographed to allow calibration of the photograph in the image analysis software.

"The distance at which a photograph is taken is very important to prevent inaccurate comparisons due to altered visual perceptions" (Louis 1992). Consistent angle of the camera to the patient also contributes to the efficacy of the wound photograph. A change of angle can change the perception of depth, shadow and make it difficult for inter picture comparison which may be required for clinical trials (Louis 1992). Image acquisition hardware chain needs to be well understood and modeled in order to compensate lens error, camera limitations such as gray level shift, blooming, clipping, IR sensitivity and imbalance needs to be considered (Belem 1999).

Standardization of digital images or photographs needs to encompass: -

1. the surroundings should be the same for each image
2. The patient's position (left or right) should be consistent
3. The flash was in one position and fixed relative to the camera.

4.6.4 Adobe Photoshop

This computer software provides the photographer with a vast array of tools that can be used to enhance an image by changing colour of image in a selected area. The colour change occurs through altering the values of the pixels corresponding to the area of interest (Clearly 1999). Computer graphics can be divided into two groups vector and raster images. All digital images are known as raster image and are made up of a collection of pixels in that location. This Adobe programme references the pixels in a specific grid and when analysing continuous-tone images e.g. photographs is able to alter the colour values to standardise the image.

4.6.4 Resolution Basics

When analysing digital images several types of resolution are important: image resolution, bit resolution, monitor, resolution and screen frequency.

4.6 6 Image resolution.

The image resolution applies to the spacing of pixels in the image and is measured per inch (ppi) e.g. an image has a resolution of 72ppi can be defined containing 4184 pixels in a square inch (72 pixels wide x 72 pixels high = 4184).The more pixels in our image the higher resolution will be. Higher resolution allows for more detail and subtle colour changes in an image.

4.6.7 Pixel Depth

Bit resolution or pixel depth is a measurement of the number of bits stored in information per pixel. Colour information is determined on bit resolution of each pixel in the file. Large pixel depth means more available colour and therefore more accurate colour representation, particularly in digital images for example a 2 –bit pixel depth would allow only 4 levels of resolution (00,01,10,11) whereas 8 bit resolution allows 2^8 (246) levels.

All monitors require at least half an hour to warm before optimum image is reached. The monitor resolution is composed of a number of dots or pixels per unit, length of output. Dots are usually measured in inches (dpi) or pixels per inch. The monitor resolution determines the size of displayed image. This should not be confused with the image resolution, which reflects the spacing of the pixels in the picture, e.g. an image with resolution of 144ppi is displayed at twice its actual size on a 72 dpi monitor (only 72 of the 144 pixels can be displayed in one inch on the monitor). The same image would be slightly larger than its original size on a 120 dpi monitor because 120 of the 144 pixels can be displayed in each inch.

The image was loaded into a personal computer using Adobe photoshop Plug software. This acquires the image by un-compressing the file. It then opens the image to full size. Theoretically this is best file that is available as no re-compression occurs as re- compression of images may lose data.

4.6.8 Image Analysis

This process is not only concerned with the image results but with the numerical or the geographical data based on the characteristics of the original image. Image analysis may also provide subjective measurements and this may be automated, for instance manufacturing of moving parts on a conveyor belt can be imaged by a camera and automatically analysed to determine if they are good quality parts or not (Baxes 1994).

4.6.9 Calibration of Image

A digital image is made up of gray tone or brightness, rather than continuously varying tones. A digital image from continuous tones can be divided into individual points of brightness described as a digital data value: known as sampling or quantitisation. "A quantitised sample is referred to as a picture element or pixel, because it is composed of digital elements of the digital image" (Baxes 1994).

Images are usually sampled into rectangular array pixels. Individual pixels have (X, Y) co-ordinates that correspond to its location within the image. The X co-ordinate is the pixels horizontal location; the Y co-ordinates is the vertical location (Baxes 1994).

The digital image is composed of a rectangular array of pixels, each representing a particular (X and Y) location and each with digital brightness data value. When these data values are collected and arranged properly they give an indication as to the brightness of the image.

Intensity calibration took place using skin tone data as background to compare normal measurements of patient's skin tone to patient's area of skin damage and grade of pressure sore.

4.7 Colour Balancing

A digital image may be processed and standardised e.g. white balancing. Photo shop was used to open the image and set a white balance using the white square on the scale in the digital image. Some of digital images required rotation by 1or 2 degrees, to line up scale to be parallel with the edges of the images. The scale had to be straight to carry out calibration of the image for accurate measurements.

Images were recorded as 1424 x 1012 Pixels. They were selected to 400 x 400 Pixels as Foster & Finlay PC Image, Image Analysis package did allow any more pixels to be opened. All files were saved as Tagged Image Format (Tif) files (a universal standard of saving files that does not involve compression). The Tif files were written to CD using a CD writer for easy storage. Image selection was copied out by cropping irrelevant data from around the sore being examined. Re-sampling images was not done because this could have changed the structure measured. Since all images were taken to place the sore in the centre selection could be carried without loss of data.

Files to be analysed were opened using PC image and to ensure consistent treatment of images, a standard ' Macro' was used. A macro is a recorded sequence of commands that are collected together run on a single instruction (see appendix 3 that lists of all Macros used in the project). The macro used for the project consisted of a calibration stage using the length scale. In all images a line corresponding to 4 centimeters was drawn using the scale on the image. Using the mouse the small areas of the sore was outlined, then the total sore area was outlined. The macro assessed and stores the image data from the outlined areas. Finally the skin tone was measured using a selected 1 cm^2 area of normal skin in the picture. All data is saved in text files, which provided the total area of skin damage, skin tone, X and Y calibration, Hue saturation, intensity and size of sore and location in relation to image origin.

4.7.1 Conversion RGB to HSI

As mentioned earlier in this chapter there are two distinctive colour models, red, green, blue (RGB) and Hue saturation and intensity (HSI). HSI has the advantage of dividing the colour out into three separate components Hue, saturation and intensity. It entirely separates the colour information from the brightness signal (Poston 1996). Whereas, the RGB the ratio values of the three channels that determine the colour making it difficult to use this colour model for analysis (Poston 1996). Once the conversion has taken place the analysis can be made largely brightness independent causing de-correlation of RGB.

Advantages of HSI

1. RGB is correlated into one measurement- Hue, saturation intensity and decoupled.

2. Separates out intensity data from colours so Hue measurement is less sensitive to lighting conditions.

4.7.2 Segmentation

"Segmentation operation is any operation that highlights or in some way isolates an individual object within an image". (Baxes 1994). Normally segmentation is automated or semi-automated and is the first step in image analysis. The segmentation divides an image into constituent parts of the object being analysed (Joyce – Loebl 1984, Gonzalez & Woods 1993).

Wound detection is very difficult as the boundaries vary within each individual image and may be subjective to the individual viewer. Many biological image analysis projects suffer from this inherent problem. In particularly due to individual different lesions, skin tones, colour separation and vague boundaries that are difficult to define. A way to overcome this is to carry out segmentation by the researcher drawing around the object of interest with a computer mouse.

Advantages

Quicker, compared to configuring an automative system. Fairly reliable and identifiable reproducible providing the researcher has been tested for accuracy (i.e. batch testing and inter batch testing). The researcher can use informed judgement as to where to measure on the image.

4.7.3 Object Detection/Binary Image

One of the geometric measurements that is produced from the macro is a binary image. All images are composed of pixels that have two brightness values, either black (0) or white (244) Baxes (1994). These values then provide the computer with a format that can be measured automatically. The image is automatically scanned from the top to bottom, left to right and each object detected ready for the researcher to clarify the object to be measured.

4.7.4 Measurements and Statistics

The full measurements of objects for sharpness, size, location, texture and grey tones, colours etc. The complexity of shapes may be simple and can be precisely measured for the dimensions and the geometrics. Two main measurements are taken from the areas in the image.

4.7.4 Geometric

Geometric measurements of the objects are calibrated to millimetres.

Area: gives the pixel area of the interior of the object.

Perimeter: The pixel distance around the circumference of the object.

Length: This pixel distance length between the major axes and point the result is a measure of object length.

Major axis Length = $\sqrt{(X_2-X_1)^2 + (Y_2-Y_1)^2}$

Where (X_1,Y_1) and (X_2, Y_2) are the major axis endpoints

Minor axis Width = $\sqrt{(X_2-X_1)^2 + (Y_2-Y_1)^2}$

Where (X_1,Y_1) and (X_2, Y_2) are the minor axis endpoints

The pixel distance length between the manor axis endpoints the result is the measure of the object wide (Baxes 1994).

4.7.6 Gray level Transformation

The Gray level of the object is measured with the gray level value of each pixel and transforms into a value that is pre determined rule independent of any of the other pixel values. For example, an x-ray has more absorbent parts of the body in the image, the less absorbent gives rise to dense parts of the image. If black = 0) and white = 244 then bone can be seen at a value of 200 upwards whereas soft tissue details are given 0-20 (Joyce Lobel 1984).

Transmission (T) is the proportion of incident light which passes through the specimen .

$$T = \frac{\textbf{Transmitted Light}}{\textbf{Incident light}}$$

Optical density logarithm of the ratio of incidents to transmitted light (formula)

$O\ D = \text{Log}_{10}\,\mathbf{(1/T)} = \mathbf{-\ Log}_{10}\,T$

The optical density scale goes from 0 (100% transmission) to infinity (zero transmission for completely opaque material). Often the area being studied does not have O.D all over. So the integrated optical density (IOD) needs to be measured:

Integrated Optical Density = *Sum of Individual O.D's of each pixel in the area being measured* = Mean O.D. X area

This formula provides an estimated absolute mass of light absorbing material to be measured in view of using IOD. Regardless of how the mass is distributed through the thickness of absorbing material e.g. the density measuring technique used by optical microscope (Joyce Loebl 1984).

Reducing a colour image to gray scale can be useful in many situations to select R.G.B. or H.S.I. image place (Russ 1998). This allows maximum scale contrast between structures being analysed in the way to facilitate gray scale image thresholding and measurements allowing a unique function to be calculated for each image that fits a line through the points representing all of the pixel colour co-ordinates in the colour space (previously discussed in this section).

The digital image value is dependent on how many bits are used by quantisation e.g. if three bits are used the brightness can be converted to one of eight gray levels.

3 bits	8 gray levels
4 bits	16 gray levels
4 bits	32 gray levels
6 bits	64 gray levels
7 bits	128 gray levels
8 bits	256 gray levels

A gray level is related to information relating to each pixel

Grey weight = Sum of pixel value for the object.

Although in an 8 bits scale there are 256 shades of grey, the human eye cannot distinguish all these different levels of grey (Russ 1998). Normal human vision can only see 10 different gray levels and hundreds of distinguishable colours. The computer hard ware for colour image processing the computer displays 2^8 or 256 different shades and may produce colours with the same 2^8 brightness values for red, green and blue components to produce 2^{24} or 16 million different colours.

4.7.7 Histograms

A histogram allows display of colour elements from images in a graph form. Each colour component is displayed separately with the gray level of each colour. The colour histogram can represent RGB space, HSI space or any other colour space. Each histogram can provide the brightness distribution, contrast and the dynamic range of individual colour components. This allows a detailed picture of colours and gray levels from the image being studied.

From the statistical information produced the brightness histogram can be provided in distributions of gray levels in the image, either in the form of a graph or a table. The histogram provides the regional contrast of the image and can determine contrast enhancement. The brightness mean and mode provide frequency figures and provide information to enable image enhancement and restoration operations.

4.8 Literature

Very few studies have been undertaken in biological image analysis predominately the research available has been carried out on pigs or only on a small number of patients. Larger studies do need to be undertaken to provide substantial data for this technology and to allow statistical significance to be demonstrated.

Hoppe et al (1999) studied 14 patients using Panasonic NVPX 100b digital video camera and used standardised lighting and Fuji colour patches for colour calibration. The images were then transferred to a personal computer. This small study demonstrated that good colour separation was possible. Standard lighting conditions were important to enable colour calibration and texture in different wounds and assessing the clinical status. The group of patients was too small to definitely provide conclusive evidence that this is an accurate method of obtaining, distributing and analysing wound images.

Various methods have been employed to evaluate the status of skin tissue. Simple visual observation of tissue colour can be useful in this regard, but human vision lacks precision, and the quantification of slow or subtle changes may be difficult to detect (Hansen 1997). The visual appearance of a wound is considered to contain a wealth of information about its cause, severity, time wise change of status and prognosis for healing (Hansen 1997).

The oldest and still the most common used method of evaluating wounds in clinical settings are direct visual examination of the injury (Hansen 1997). Hoppe (1996) a pilot demonstrated that up to 80% of all simple digital image processing techniques are capable of correctly classifying infected and non infected wounds.

There is little research available in image analysis and this could be attributed to the technology being extremely expensive and which deters people from using it unless they have financial support for their project.

The Oztunk et al (1994) study involved one pig using two methods of image processing to compare the effects of different dressings on pig wounds. The wound areas were determined by standard thresholding and pixel counting. Cameras were placed at each end of the pig to allow different views of the wound. This gave data on the healing processes and area measurements. The second method involved 3D construction to allow a better comparison and more insight into healing dynamics. It was demonstrated there was a good correlation with manual methods. However, wound edges were difficult to define. This study concludes that image processing is a reliable, objective way to evaluate the physical measurements of skin wounds. In a comparative study structured light did not provide the same type of data that may be used as a non-invasive technique for measuring wounds on animals.

Cohen et al (1998) investigated granulating wounds and how skin grafts can be measured using a granulometer. The granulometer is based on colour coding for wounds which allowed easier definition and a standardised way of documenting wounds (Cuzzell 1988). The granulometer was designed to facilitate a finer assessment and standardised documentation of wound healing. The granulometer scale was devised using eight 0.4 x 0.4 cm photographs of wounds in different stages of healing and these were placed in line next to each other in ascending order of wound healing. 22 wounds in 20 consecutive patients were studied on a plastic surgery unit. Swab cultures were taken 10 days prior to surgery. Topical treatment was given using sodium hypochlorite to treat staphylococcus and streptococcus and pseudomonas. Where no organism were present a hydrocolloid dressing was used. One single dose of prophylactic cefonicid antibiotics was given one hour before surgery. Measurements were taken of blood, haemoglobin transcutaneous oxygen saturation and measurements of the wound by the surgeon divided into sub areas of varying grades of granulation. The wounds were then scrubbed with povidone-iodine superficially scraped with a blunt instrument then a graft harvest was taken from the thigh. Seven days later the viability of the graft was evaluated and graded against a 4 grade scale see below:

Grade Number	Description of skin graft
1	Necrotic
2	Pale: viability is doubtful
3	Pale pink possible graft take
4	Pink: good take
4	Pink Red: take is certain

The surgeons were blind to the initial assessment. The inter-observer variation was also tested with the granulometer and against photographs. It was demonstrated that the graft takes were good in at least one half of the patients and the rest were contaminated. Granulometer scale grade and the skin graft grade was plotted. This had a Spearman correlation co efficient 0.94 which is statistically significant between the Granulomter scale and skin graft. It was demonstrated by the Mann-Whitney nonparametric U test that the adjacent grades had a non significant difference and predictability values of graft take in most of the comparisons. Inter observer variation was very low. Eighteen of the twenty-two wound zones were given the same simultaneous grading by three surgeons using the granulometer. The inter observer variation was assessing by photographs of the same wounds on two separate occasions two weeks part. All nineteen areas were given the same granulometer grade twice by three of the surgeons

The granulometer has demonstrated that it can overcome the problem of human inaccuracies of wound assessment and colour classification. Skins grafts can now be accurately graded using this 8 scale method. The authors believe this can be extended to assessments of wounds during yellow and red phases. As it simplifies wound assessment whilst also giving accurate reproducible and reliable tool for the practitioner.

Boardman et al (1994) investigated colour changes that occur during wound healing and a more informed way of colour classification. In a small study of 10 patients over an eight week period all treated with silastic foam with photographs taken at a weekly interval. Analysis was carried out on the photographs using hue saturation and intensity. It was demonstrated that the red Hue of the wounds studied, had subtle changes in the continuous percent of Hue colour traces that can indicate problems occurring within the wound. The colour within wound healing can be an indication of the biological condition of the wound. For example high values of mid range percent red Hue can be linked to periods of wound infection. HSI colour representation, therefore appears to provide an improved way of analysing wound colour as opposed to using RGB models.

Hansen (1997) investigated a small group of 24 pigs and inflicted 12 injuries using metallic pads against the pigs skin for 2, 4 and 10 hours using cooled or heated temperatures (24°c) – 40°c. Wounds were followed up for a period of 27 days and colour images were taken of each site along with visual appearance. Laser Doppler measurements were made, of skin temperature and physiological data. Tissue damage was assessed histological at days 4-7. Colour analysis was obtained using a video camera and this was then sent to an IBM 486 and converted into RGB and then to HSI. An attempt was made to relate Hue saturation and intensity with the wounds severity. However, the raw signals of HSI, did not possess a direct linear correlation with traumatic indexes. However, again the severity of the wounds were pronounced and total thickness and shallow wounds demonstrated statistically significant with the validity of 90% confidence. Visual skin colour changes also correlated with wound severity.

4.9 Conclusion

Image analysis has been in existence for some forty years and is increasing present in our daily lives. Hue is a pure colour e.g. yellow/orange, Saturation is the degree of pure colour mixes with white light and Intensity is the combination of the colour picture. Studies that have been undertaken in wound care are insufficient to improve the benefits. Larger studies do need to be undertaken to provide substantial data for this technology and to allow statistical significance to be demonstrated. A reliable and valid method of measuring wounds needs to be developed and image analysis appears to provide a useful tool to undertaken this.

Chapter 5

The Importance Of Wound Documentation And Classification Of Wounds

Chapter 5

Nursing Documentation

The management of wounds is traditionally a nursing problem. Doctors only become involved on the ward rounds or when there is a problem, and rarely on the re - dressing of wounds. Accurate holistic wound assessment needs to be made by the practitioner and this will require many skills. Dealey (1994) states that the ability to make an accurate assessment of the patient's wound is considered to be an important nursing skill. Holistic wound assessment provides a baseline upon which to focus the plan of care, set relevant goals and apply relevant wound care products to promote healing (Briggs 1995, Williams 1995). Inferior wound assessment can result in inappropriate wound management and consequently result in increased costs in nursing time and use of products and patient suffering (Williams 1995). In the past, nurses have not employed evidence based nursing practice but employed anecdotal evidence. However, in recent years this has started to change and nurses now challenge old ritualistic care.

The literature demonstrates that nurses need to document of wounds and need assessment forms to provide a framework upon which to base the assessment (Morison 1992, Dealey 1994). Morison (1992) states that accurate observation of wounds can be made easy by the use of a chart which highlights the factors needing consideration when wounds are being assessed. These are also an aid in teaching student nurses.

Accurate documentation of wound characteristics enables comparison of the wound assessment by the nurse involved in patient care Benbow (1995). Correct wound assessment is dependent on an understanding of the physiology of wound healing, the factors which delay the process, and the optimal conditions required at the wound surface to maximise healing (Flanagan 1996, Kerstein 1995). A holistic approach to wound management needs to be employed to monitor the rate of healing and the effectiveness of the planned care at promoting healing. Wound assessment is problematic as it is very subjective and is only as good as the practitioner undertaking the assessment. Therefore, if the practitioner's knowledge is deficient in the stages of wound healing, they may be unable to correctly identify the wound status (Flanagan 1996) and the consequence may be an inappropriate dressing selection.

The UKCC code of conduct pronounces that nurses must " take every opportunity to develop and maintain his or her professional knowledge and competence". Nurses have a duty, therefore, to attend study days and read relevant literature where they consider their own knowledge is deficient. However, nurses are now having to undertake study in their own time and often have to finance courses themselves. This should not necessarily be a reason why a nurse does not update her knowledge as most Trusts provide in - house courses. Since not all ward nurses can be trained, it is necessary to rely on a few speciality trained individuals (Link nurses). These nurses require adequate provision for study leave (including funding), which ought to be provided by employers. Link nurses in tissue viability / wound care are a valuable source of knowledge to a ward and provide a resource for the ward members.

Morison (1992), Flanagan (1994), Moody & Bennett (1994), state the importance of maintaining clear concise nursing records. Failure to do so can be seen as a negligent act and a breach of nurses' duty of care. An agreed nationally applied system of wound assessment forms would provide a useful framework and assist in documentation. Since no pressure sore grading system has been nationally agreed this maybe some time in coming.

Only one small study, of 120 patients with 152 wounds, on the documenting of wound management has been undertaken by Briggs & Banks (1995) in a teaching hospital in Leeds. All the wounds required healing by secondary intention, e.g. pressure sores, leg ulcers and infected wounds and were graded on the Association of Enterostomal Therapists'grading system and the care plan reviewed. The first review revealed that in nursing records only 56.2% had outlined treatment for pressure damage. Consequently, a group was set up; new wound care guidelines and a documentation form were designed based on Morison (1992) and Dealey (1994). The audit was repeated with a sample of 136 patients with 152 wounds. Great improvement had occurred and 99% of patients had a designated care plan. The assessment appeared to be more thorough when the new wound assessment form was used making information available at a glance. However, as in our experience with pressure sores, the first assessment may have been completed very fully, but reassessments were completed very poorly in regard to dressing changes and renewals.

This study clearly demonstrated that nurses completed the wound assessment form but did not understand the importance of reassessment and accurate record keeping as advocated by the UKCC 'Standards of records and record keeping (UKCC 1993) and "the NHS Executive keeping the record straight" (1993). Nursing records are the first source of evidence investigated when a complaint is made. Nurses need to keep this in mind when documenting. Hammersley (1991) states that nursing records produce a documentary description of the patients' stay in hospital and the nursing record is considered to be a concrete display of professional competence.

The indices for wound assessment and classification encompass many characteristics, e.g. wound classification, wound size, wound edges, undermining, type of tissue present in the wound, exudate, condition of surrounding tissue (Hampton1995). The healing process is a complex mechanism and conceivably this is why no standardised approach has been adopted. Flanagan (1995) suggests that if a standardized approach could be adopted it would allow competent understanding for all practitioners, easy comparisons for wound evaluation, accurate documentation, and ultimately provide the patient with cost effective wound care and reduce suffering resulting from the wound. In America the National Pressure Advisory Panel and the Agency for Health published guidelines for prevention and treatment of pressure sores. Lazarus et al (1994) states that The Wound Healing Society published guidelines for assessment of wounds and evaluation of healing. Gentzkow (1995) commentated that the guidelines were deficient in clarity on how to assess wound healing during clinical investigations.

5.1.1 Computer Documentation.

Over the last ten years the computer has become an important tool in the health care setting. Queen's Hospital was one of the first pilot sites six years ago for the Government's computer in health care projects. Specifications were drawn up for each department and what they would require a computer system to monitor (Russell 1998).

The Tissue Viability Nurse Specialist worked jointly with the Trust's Infection Control Nurse to devise the contents of the *"wound assessment screen"* The Tissue Viability Nurse required wound type and size; description; stage of healing and the wound care product being used. The Infection Control Nurse required the signs of wound infection on admission and discharge, whether the patient had a temperature, and if their wound infection was treated with antibiotics. This data contributes towards on - going surveillance for infected surgical wounds.

The wound care screen (figure 5.1) permits documentation:

- Wound bed
- Type of wound
- Site
- Size
- Hospital acquired
- Pressure sore grade using the Torrance grading system
- Classification of the wound
- Wound Margins
- Cleansing agent
- Dressing applied
- Antibiotics

The lookup from the dictionary enables the type of wound to be selected e.g. chronic, leg ulcer, pressure sore, surgical and trauma. The wound site and description are also selected from a lookup lists. The pressure sore grades are only used for the pressure sore and not for wounds in general. Some practitioners use a stage system such as Torrance (1985) to define wounds.

The wound care screens are accessed in the Nursing module from the "*main menu*" (figure 5.2). Initially the nurse enters the problem in the care plan e.g. a pressure sore or wound. A core plan of care will then appear on the screen that the nurse customises to the individual patient. Subsequent documentation is undertaken via the "*document intervention screen*" and allows documentation of wounds to take place each time a wound is redressed. The system currently permits six wounds to be

Figure 5.1

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Wound Assessment II

ASSESSMENT OF WOUND BED

Type of Wound (3): Site (3):
Description (3): Size (3): cms.
PRESSURE SORE: Grade(3): Hospital acquired(3):

*** Epithelialising *** PINK
Pink, epithelial cells, healthy.

*** Granulating *** RED
Shiny: Bright Red:
Granulating Tissue:
Connective Tissue: Capillary Loops:
Serous Discharge:

*** Sloughy *** YELLOW
Slough: Soft necrotic tissue: Yellow:

*** Necrotic *** BLACK
Black/brown: Dead tissue:

*** Infected *** GREEN
Inflammation/redness:
Localised heat: Localised pain:
Offensive smell:
Pyrexia 38C or above:
Purulent Discharge:

*** Wound Margin *** (Surrounding Skin)
Healthy/intact: Erythema:
Fragile: Dry/scaling: Oedematous:
Macerated: Bruising:

Cleansed with:
Dressed with: Antibiotics:

Figure 5.2

NURSING MAIN MENU - 4.6

0. EXIT

——PATIENT CARE——
1. ASSESSMENTS
2. ENTER/EDIT ORDERS
3. ENTER/EDIT CARE PLAN
4. PROCESS INTERVENTIONS
5. PATIENT NOTES
7. NURSES PATIENT LIST HANDHELD enter/edit

——CARE PATHWAYS——
50. CRITICAL PATH SPREADSHEET
51. VARIANCE MENU

——PRINT——
11. PATIENT PROFILE
12. PATIENT PLAN OF CARE
13. PATIENT AUDIT
14. TPR/BP CHART
15. PRINT NURSE DISCHARGE LETTER

——OTHER——
30. COPY CARE PLAN

——VIEW——
21. PCI
22. VIEW PLAN OF CARE
23. VIEW ASSESSMENTS
24. NDX LIBRARY
25. NURSING REPORTS
26. UNVERIFIED CARE PLAN REPORT

User: RUSLJ.SNEA *LIVE* Mail: 26*

documented but there are plans to increase this, as there are occasionally some patients that have more than six wounds. The nurse can also add additional information in the patient's notes in the *"nursing module screen"* "like dressing did not stay on" or "due to incontinence" or "patient has been photographed, as the pressure sore is very deep".

After the introduction of the wound screen it was realised that definitions of the wounds required clarification. Definitions were placed in the internal mailing systems (Mox) in the library files on Epithelisation, Granulating, Sloughy, Green, Yellow, and Necrotic (Dealey 1994) alongside the "Wound Care Guidelines" which are available in the library for easy reference.

Increasingly computer systems are being introduced and consequently more nurses will be using computers to document wound care interventions. The system used at Burton facilitates auditing of dressing products and the type of wounds being assessed. Other hospitals will realise the benefits and then will convert.

5.2.Wound Classification

Several methods of classifying wounds exist (Cuzzell 1988, Healey 1995, Xakellis 1995). The literature reviewed has not revealed the existence of an international, or even a national wound classification system. The classification of a wound depends on the knowledge of the practitioner of the physiology of the skin (Flanagan 1995). Direct observation is the most widespread method of assessing and classifying wounds by the colour and characteristics of the wound surface (Cuzzell 1988). Bunting (1996) argues this approach is over simplified, but in reality it is easy and quick to use and has no cost implications. Some practitioners use a stage system such as Torrance or Shea to define wounds. However, Xakellis (1995) states that the staging system works well initially for ulcer assessment, but is inappropriate for long term assessment of healing. "Pressure ulcers do not heal in reverse stages" (Makebust 1995). For instance, a stage 4 ulcer does not also progress to stage 3 and subsequently through stages 2 to 1. As discussed in chapter 2 (Russell 1998 (b) pressure ulcers heal through a process of granulation, wound contraction, epithelisation and scar formation (Xakellis 1995).

Xakellis *et al* (1995) reviewed three strategies proposed by The Agency for Health Care Policy and Research, Wound Healing Society and the Pressure Sore Status Tool. There were twelve measures recommended by the three groups (figure 5.3) which were taken from the empirical evidence supporting effectiveness. These measures represent expert opinion regarding the clinical monitoring of the important changes that occur during ulcer healing. The authors acknowledge that the eleven points may not fulfil all practitioners' needs. Furthermore, not all the measures necessarily may be required to assess an ulcer. Wound classification commonly employed in England is the pink, red, yellow, green and black system, initially launched in the mid - 1950's by a company called Lederle,

Figure 5.3

Clinical measures recommended for monitoring ulcer healing

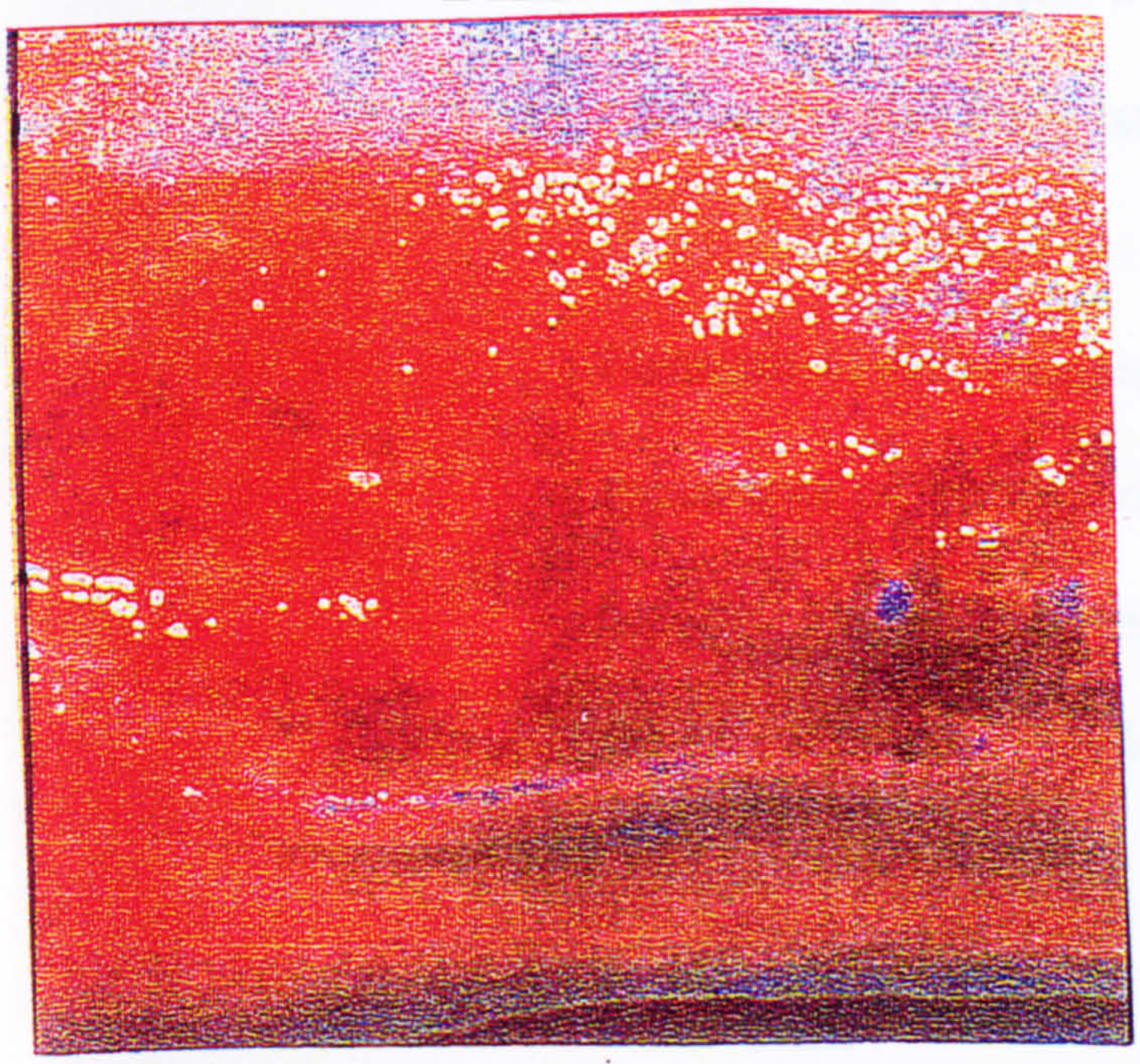
Wound factors	Size/area
	Stage/depth
	Location
	Shape
	Exudate
	Necrotic tissue
	Granulation
	Epithelialisation
	Sinus
	Skin edges
Surrounding skin factors	Erythema/skin colour
	Induration

Adapted from Xakellis and Frantz (1997)

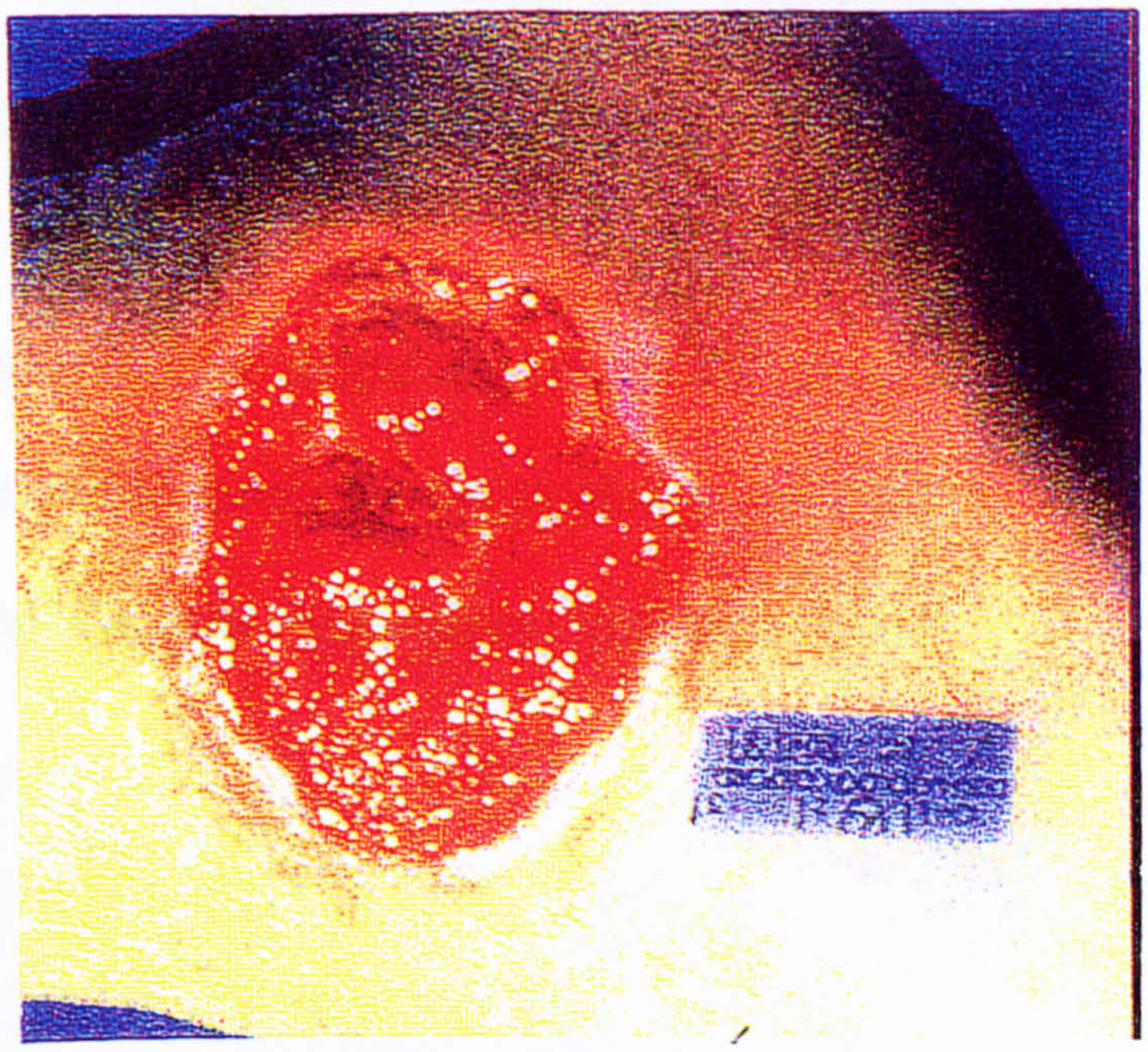
Figure 5.4

Wound Classificatiom

Pink



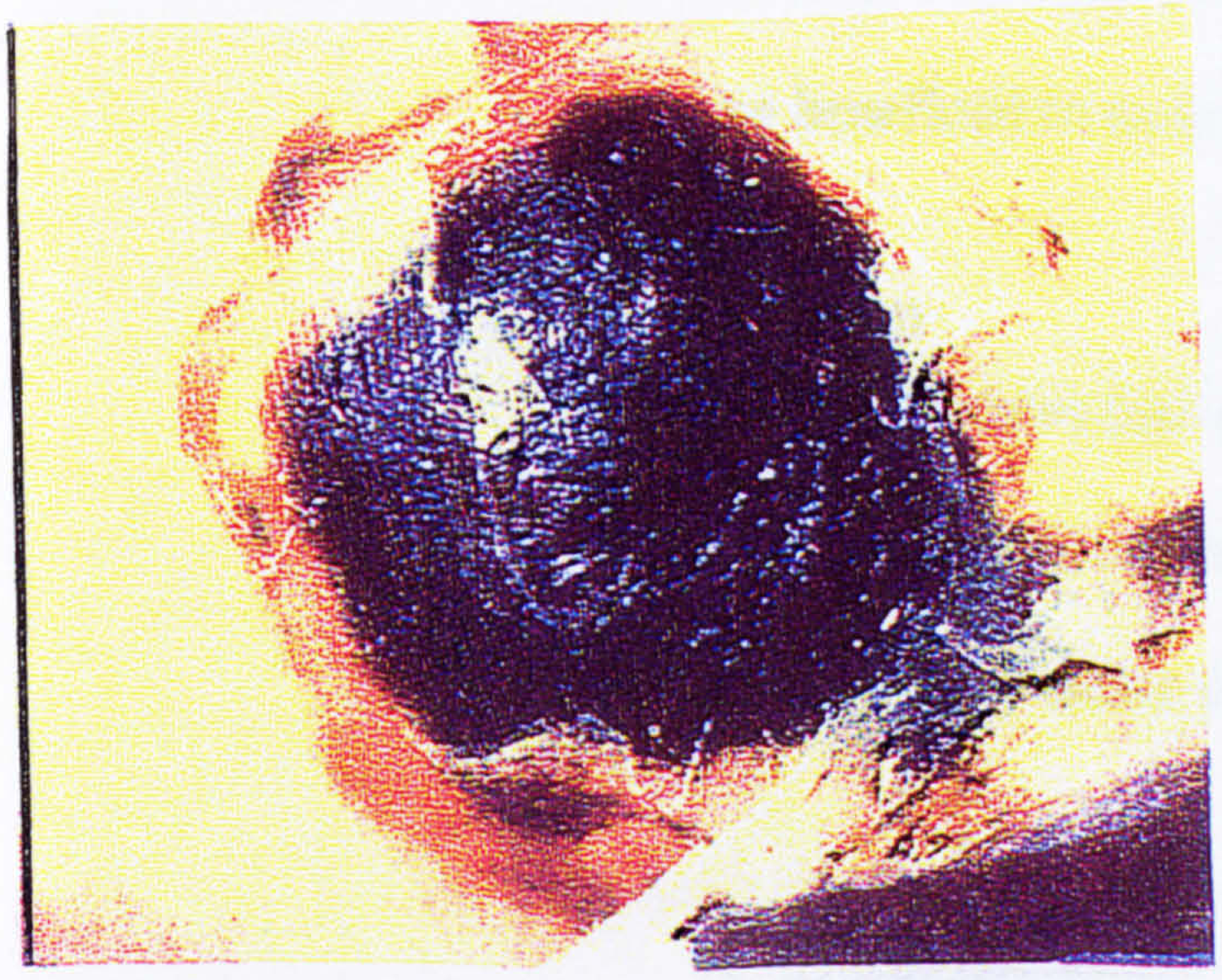
Red



Green

Yellow

Black



Photographs from ConvaTec

in line with recommendations that Varidase is indicated for use on necrotic wounds. This system was then adopted by the Wound Care Society in 1988 and is still the most common method used and taught (figure 5.4).

Flanagan (1995) suggests a classification model based on the clinical appearance of the wound and the requirements for the promotion of wound healing. Research is required to discover how nurses actually classify wounds in clinical practice.

5.2.1 Pink

This is healthy tissue in the final stages of healing. Pinky white epithelial tissue migrates from the wound edges and the tissue will contain remnants of hair follicle in the dermis (Flanagan 1995, Hampton 1995).

5.2.2 Red

This tissue is deep red or pink and has raised uneven red granules giving the tissue a "beefy appearance". Fine capillary loops have been laid down and consequently this tissue can bleed easily. Hohn et al (1995) state that unnecessary cleansing of granulating wounds can cause more harm and it is more beneficial to maintain the optimum environment for healing.

5.2.3 Green

Collier (1994) states that green exudate does not always indicate clinical infection as bacteria can colonise in wounds without harming the host. However, green exudate may demonstrate that Pseudomonas are present in the wound bed. Pathogenic organisms can delay wound healing and the wound may demonstrate signs of clinical infection such as inflammation. Exudates from clinically infected wounds range from yellow, green, dark red/brown grey (Hampton 1995). Where an infection is suspected, a swab should be taken to identify the organism causing the infection.

5.2.4 Yellow

This tissue comprises of the remnants of dead cells from the wound surface. The debris contains large amounts of dead leukocytes, bacteria, and fibrous tissue, and these give the tissue a yellow creamy appearance. Flanagan (1995) states that slough are a natural part of healing, but does necessitate rehydration with a hydrogel. The presence of slough should not be taken as an indicator that the wound is not healthy, but that the wound is removing dead tissue to make way for healthy tissue.

5.2.5 Black

This tissue comprises hard black/ brown leathery eschar in appearance. Xakellis (1992) demonstrated that necrotic tissue at baseline was associated with slower healing times. This tissue has to be debrided before any wound healing can take place. The quickest method of debridement is surgical, but usually requires an anaesthetic. Conservative measures are rehydration of the tissue by scoring the tissue with a blade and allowing the hydrogel to hydrate the leathery tissue. Another method, which has gained in popularity, is the biological larvae therapy (maggots) (Hampton 1995).

5.3 Wound Specifics

Regardless of which wound assessment model is employed, the case history should be carefully studied to determine how long the wound has been present, its location, the state of the surrounding skin, and whether any undermining and tracking is present. Other factors, extrinsic and intrinsic, have to be examined, as these will also delay wound healing (Hampton 1995). The final picture is gained when size, colour and measurement of the wound have been obtained and only then a plan of care can be made.

When assessing a wound, measurements must always be taken the same way (length and width in centimetres) with a tape measure. To increase reliability of results always measure the largest and widest aspects of the wound or measure *from head to toe and side to side of the wound* (Cooper 1992). For the practitioner to decide if effective wound care is being applied, measurements need to be taken to evaluate the wound's progress. Rijswijk's (1994) study demonstrated that "there appears to be sufficient evidence to suggest that weeks of ineffective treatment modalities can be avoided if appropriate clinical assessments are performed at least once a week". The patient needs be on the same side and in the same position to enable precise documentation (Plassman 1995, Bates - Jensen 1995, Melhuish 1994).

Area two-dimensional and may be measured by multiplying length and width of the wound or may be measured more complex / accurate way. Methods vary from very sophisticated photography and planimetry, or computer imaging to tracing on acetate. Volume, which is three-dimensional, is estimated by the length, width and depth measurement or may be measured by moulds, stereophotography, MRI or ultrasound. These methods tend to be employed for research projects to detect changes in the wound.

5.3.1 Wound tracing

The most popular and cheapest method of assessment is by tracing onto transparent sheets marked with grid, which is transferred to graph paper, or the acetate placed in the patient's notes (Plassmann 1995). Transparencies tend to be more accessible on wards and this may be the reason why it is the method preferred by nurses. Additionally, it is the least time consuming of the methods mentioned above. This method, as it is dependent upon the observer being able to define the wound edges, is very subjective and depends on clinical judgement (Raminez 1969 & Majesko, Flanagan 1995). Despite this, it is the most common method taught in the classroom, and it is far better to have some documentation rather than none. Measurements of wounds should be encouraged as it is an integral part of the assessment tool and must be recorded as it is important for medico-legal reasons (Moody 1993).

Wound tracing, however, does have limitations in that wounds are three-dimensional and tracing gives no information as to depth. However, if this information is recorded separately the tracing this will provide an overall evaluation of how the wound is progressing (Flanagan 1995). Anthony (1985) suggests that wound tracing is less reliable with regard to inter-observer error. The best way to overcome this problem is to have the identical observer enabling the same method to be employed.

Various methods of evaluating wound tracing have been undertaken such as tracing the wounds and then counting the number of grid squares covering the wound (Gowland 1983), tracing the wound areas onto acetate sheet, cutting the shape out and weighing it (Crisculob 1988). Sterophotogrammetry is used to measure rates of healing (Bulstrode 1986) and is the use of two cameras simultaneously. These two photographs are then analysed using a sterocomparator, which produces a three – dimensional picture by combining the photographs (Anthony 1985). All of these methods are very time consuming but have proved to be accurate.

Kudin (1985) designed a gauge, which measures length and width of a wound in one single measurement, and in 1989 he produced the empirical formula: which assumes a wound is irregular and that only 55% if the "squared area" is wound.

Area of the wound = length x breadth x 0.55

Thomas & Wysocki (1990) demonstrated a correlation between the gauge, acetate tracing and photographs. The Kudin ruler was found to under estimate the wound area by several orders of magnitude (Plassman 1995). The ruler systems set the standard for the measurements of wounds, despite the fact that they are the least reliable method and gave a high standard deviation, making the system unacceptable for research trials.

5.3.2 Computers and Wound Measurements

Over the last ten years the use of computers has increased considerably, particularly in wound measurements. A tracing taken of the wound can be transferred into a computer and the image can then be analysed automatically (Ahroni & Boyko, Brohannan 1983, Anthony 1985, Majeske 1992). Palmer *et al* (1989) used a camera linked to a computer to measure wound area. However, it was discovered that a camera angle of 20 degrees to the perpendicular resulted in a reduction of the measured area by approximately 10%. Thus care must be taken to standardise photography technique.

Computer analysis is a simple and reliable way to accurately and reproducibly measure wounds. It has proved far more reliable than manual measurements, which had as much as 25% variation on repeat estimations between observers whereas computer measurements had less then 0.2%

deviation on re-measurement (Mekkes J et al 1992) (see Chapter 7). Current data suggests that measuring the ulcers dimensions exudate and predominant tissue in the ulcer will provide the most valid indicators for monitoring the change in pressure ulcers over a time period. One of the major problems with trying to measure a wound is the natural curvature of the body as all the tools are designed to measure wounds as a flat object and consequently will be inaccurate (Plassman 1995).

Taylor (1995) studied various shapes i.e. circles, rectangles, polygons, traced by a computer program *"mouseyes"* with five volunteers, 3 male and 2 female, four right handed and one left handed. A mouse was used to trace image outline, which was then stored on to the personal computer. The program was designed to digitise the perimeter of an image and then calculate the surface area within it, and also to calculate the linear distances between features within an image. The results demonstrated that this system's accuracy was an error of 1.3% (which was less than Taylor's (1995) studies which had a 2% error). This work highlighted problems with shapes < 1cm^2. Taylor suggests magnification would solve this problem. Several measurements had to be taken but this was not always practical with patients enlisted for research. Angular shapes posed particular problems as their straight sides need to be aligned with the vertical and horizontal axes. Further work is required to improve the system so that it is more accurate and reproducible.

Melhuish et al (1994) investigated fourteen patients, 5 with pilonidal sinus excision and 5 with abdominal wounds cavities after surgical procedures. Wounds were evaluated at weekly intervals using light measurements for the area, volume and depth. The wound edges were highlighted with a mouse, and the computer calculated the number of pixels in the area being studied. Results demonstrated a correlation between volume and circumference using the Gilman (1990) formula to standardise the measurements. One criticism cited by the authors is the problem of measuring the area and volume with any degree of exactness due to the location of the wound. As a result of the correlation of wound circumference to the wound area and volume, it is possible to monitor a wound is progress by the circumference.

5.3.3.Hue Saturation and Intensity

Hue saturation and intensity (HSI) analysis please refer to chapter 4.

To the best of my knowledge, there are no studies using HSI for measurement and classification of pressure sores in the literature. Boardman M (1993) studied 10 patient 8 patient healed normally and two had wound infections. Various infected wounds were studied abdominal wounds, groin abscess, and pilonidal excisions. Healing was measured using image analysis and reported that HSI analysis provides improved means of identifying wound areas. He demonstrated that subtle changes in the continuous percentage hue colour traces can indicate problems in the wound.

A recent study on a burns patient using colour imaging discovered a high correlation between wound severity and HSI at 5 - 5 days. It is concluded that this method could be used for tracking wound severity in a clinical setting (Hansen G et al 1995).

5.3.4 Wound Depth

The depth of a wound can by measured in a number of ways e.g. sophisticated stereophotography, ultrasonic scanning and probing the wound with swab and examination with gloved finger (Krasner 1992, Plassman 1995, Flanagan 1995). Techniques employed in research are unsuitable for the clinical area and every day use (Franz & Johnson 1992, Gentzkow 1995). Dimensions of a deep wound should be measured using a cotton tipped applicator to enable gentle examination. The other practical method of assessment of deep wound is a gloved finger (Cooper 1990). Both of these techniques are subject to a degree of accuracy dependent upon where the measurement is taken, as this needs to be repeated on reassessment.

5.4 Photography

"A good photograph is worth a thousand words" –

Louis 1992, Haplin-Laundary 1994

Over the last few years photography has become a popular method of recording wound progress. One reason is that good quality pictures, are particularly useful in the light of increasing legal cases! Photographs also provide a detailed picture of the wound. Photography provides a permanent record and successive pictures can be compared for improvement or deterioration purposes (Anthony 1985).

Louis (1992) suggested that "Word description and observation of wounds does not provide a complete overall picture. However, a photograph taken correctly can say it all". Another advantage of using photographs for patient care is that the effects of treatment can be monitored closely and clinicians do not have to have the dressing removed unnecessarily. It is prudent to not only take a photograph but also for measurements and charts of the wound to accompany this information in the documentation of the patient.

The distance at which a photograph is taken is very important to prevent inaccurate comparisons due to altered visual perceptions. A consistent angle also adds efficacy of the wound being photographed (Louis 1992). Patients may also be motivated by improvements seen in a set of photographs from week to week. This can act as positive reinforcement and help patient's motivation to participate in the plan of care.

A photograph of a patient's wound provides an unambiguous image for clinical reimbursement and legal purposes. This is particularly pertinent in America as more litigation takes place there.

A patient's photograph that was taken on admission showing damaged skin integrity is evidence that can be used when investigating a complaint and to clarify the situation if there is doubt. It is therefore advisable that more photography takes place on admission if the patient's skin is compromised by any damage, which has previously occurred in the community. Photographs cannot only help the documentation within all health care settings but can be used to educate patients, families and other health care professionals.

For the best results, medical photographers should be used, as they are trained to take consistent photographs, which allow comparisons between photographic images over period of time (Melhuish 1995). A professional photographer will consider whether the detail can be clearly seen and if the wound will be in the centre of the picture with good background and lighting. An auto focus camera is not the ideal but it is better than no documentation and is relatively inexpensive to purchase.

The Polaroid camera is portable and has the facility to standardize the distance making evaluation effortlessly. The advantage of this method is that the photograph is instantly produced with a grid but no reprints or slides can be made. When taking photographs for whatever reason always obtain the patient's written consent, particularly if you wish to make slides or publication at a latter date. Flanagan (1995) states that if you chose to take your own photographs, some common rules need to be followed:

- Patient identity should always be kept confidential
- Never use the camera to take close up shots of the wound
- The background needs to be green to provide a contrast
- Subsequent photographs need to be taken in the same position
- Photographs need to be stored in a secure place

5.5 Conclusion

Nurses play a crucial role in wound management and therefore needs to have the skills and knowledge of wound physiology, assessment for the stages of wound healing for accurate documentation. The form of documentation is not important whether hand written or computer. The clear terminology is very significant and using a standardised charts sizing and colour classification and measurement of wounds allows easy evaluation from one practitioner to another. There numerous methods of measuring wound and some methods are only practical for research and not every day use in ward area. Appears that the most commonly employed is tracing the wound and counting the squares and placing in the patients notes. The limitations of each tool have to be carefully considered. One of the best documentation is a photograph as this can be used in legal case and can not be miss interpreted with good documentation of notes. With every advancing technology more new techniques will become available in the research area but for every day use it needs to be simple and quick so that it does not intrude into the nurse's increasing workload.

Chapter 6

Randomised Comparison Clinical Trial of Pegasus Cairwaves mattress & Proactive seating cushion and Huntleigh Nimbus 3 & Aura seating cushion

Chapter 6

Randomised Comparison Clinical Trial of Pegasus Cairwaves mattress & Proactive seating cushion and Huntleigh Nimbus 3 & Aura seating cushion

The primary aim of my study Randomised controlled trial of 141 Care of Elderly Patients who were assessed to have Torrance grade 2 and above pressure ulcers (71 on Cairwave, 70 on Nimbus 3) was to determine whether there were significant differences between the Pegasus Cairwave Therapy System & Proactive 2 Seating cushion and Huntleigh Nimbus 3 & Aura cushion. The secondary aim was to determine whether availability of extra pressure relief equipment would reduce the incidence of ulcers in an acute hospital. We used digital photographic recording of pressure ulcer development / progress as well as visual assessment of healing.

6.1 Method

This was the primary study that investigated randomly the effect of two types of specialised pressure relief systems (Pegasus and Huntleigh) using a randomised allocation of beds and seating cushions (mattresses and cushions from the same manufacturer were to be used at all times). The aim was to recruit enough patients to each group to ensure that at least 100 patients were discharged alive from each system. Patients were considered for trial inclusion. On admission to the Health Care of the Elderly unit with a pressure sore of grade 2 and above (on the Torrance Grading system). Written consent was obtained from the patient or from the next of kin where patients could not consent (see appendix 1). Explanations of the trial were given and an explanatory leaflet was given to the patient or relative (see appendix 2). The consent form included permission to take photographs of all sores and to publish photographs in scientific journals and to allow copies of photographs to be given to participating companies provided that no identifying details were included. Patient were randomly allocated a Pegasus Cairwaves or Huntleigh Nimbus 3 mattress and matching seat cushion. Randomisation of patients was achieved by providing each ward with a set of opaque envelopes numbered consecutively to ensure no envelopes are missed. When a patient was to be randomised the first envelope was opened and a similarly numbered sheet of paper indicated which type of bed to assign to the patient. The allocation of bed types to each number were created by a computerised random number generator.

In addition to manual measurements of pressure sores we also monitored the Waterlow score (1988), the Burton Score (a locally derived nutrition indicator, Russell *et al* 1998) and collected data to allow us to investigate the possibility of using simple pathological markers (e.g. serum albumin, or haemoglobin) as extra markers of pressure sore risk. These results were monitored on a weekly basis. Patients were monitored weekly using digital photography: A gray scale with a measurement scale to calibrate for the image analysis and the patients trial number was included in each image. Patients were followed up until the pressure sore had healed and they no longer required pressure relief equipment, or they were discharged into the community, or they died. Any patient that withdrew was also followed up on a weekly basis until they were discharged. Previous studies (Devine 1995) have treated patients who died separately from those who recovered when analysing benefits of pressure relief: we envisaged using a similar protocol to prevent biasing the analysis, hence our plan to recruit 200 patients who would be discharged alive. A placebo group was not used because it would have been unethical to expose patients to the risk of pressure sores when the natural history of any such development is well known.

The second phase of the study was to carry out in depth analysis using the image analysis macro (Macro list to of all variants see appendix 3) measure the healing rates of the pressure sores against the manual measurements. This package will also study Hue Saturation and Intensity (HSI see definition chapters 4 & 9) of each pressure sore. To test the precision of the researcher batch testing was carried out on two separate images thirty times. The research would then use these two images to test their precision each day prior to image analysis commencing.

Patients were also asked their opinions on the comfort of the bed. Patient questionnaires were carried out only after the patient has been on a mattress for one week or if the patient had been withdrawn from the trial for their own reasons. An independent person from Clinical Audit undertook the data collection.

6.1.1 Hospital information support system

The nursing order entry system in HISS allowed nurses to identify patients suitable for the trial by enabling them to place an order for the Tissue Viability Nurse Specialist to visit the patients. It was also possible to schedule photographer's visits using the system. The system permits viewing of patient details before patient consultation, which ensured the Tissue Viability Nurse Specialist / research nurse knew some history before speaking to the patient. Data collection forms for the trial were also provided in the order entry module. The internal mailing system was also very important and facilitated communication between the study wards and the Clinical Audit Department. The trial co-ordinator monitored the use of the equipment via the HISS on a daily basis. A log was kept on HISS of any equipment that became faulty or needed servicing. Finally, after one year all the companies carried out preventive maintenance servicing of their own equipment which was logged on HISS.

6.1.2 Economic Evaluation

A cost economic evaluation was included in the study plan to include the following:-

- Total cost of mattresses
- Cost of dressings

- Sore progress and deteriorating ulcers
- Subjects opinion of comfort
- Nursing staff consensus of opinion of the equipment and patients comfort

6.1.3 Infection Control

Mattresses that became contaminated by MRSA were cleaned according to hospital protocols or returned to the manufacturers in return for a replacement unit, if control of infection policies demanded.

6.1.4 Rationale behind method

Assuming an average length of stay on the care of the elderly wards is 18.25 days (this length of stay was initially estimated by a consultant geriatrician based on clinical experience and was confirmed by routine bed occupancy stats), and 100% occupancy, each bed should be occupied by 20 patients / year. On 13th August 1996, 10 Airwaves beds were available in the Trust and occupied by elderly patients translating to 200 elderly patients / year using pressure relieving mattresses. The availability of pressure relief equipment in Queen's Hospital is limited (ten mattresses) and from clinical experience it was believed that more patients should be placed on special mattresses than currently were available. We therefore estimated that our target of 100 live discharges per group could be achieved after a trial period of approximately one year. Assuming 100% pressure relief bed occupancy and no withdrawals or deaths, this would require 5 pressure relieving mattress per group. Since the target would almost certainly be unachievable we estimated that 40% over -availability of equipment should be sufficient. Therefore, the companies were asked to provide 7 mattresses and seating cushions each.

Unfortunately the death/ withdrawals rate had peaks and troughs in the equipment requirements and meant that our 40% estimate was too optimistic and the study had to extend by 6 months to confirm statistical significance. The total number of patients that completed alive was 112 and when dead patients were included the total was 141 (dead and live 'completing' the study). Further details will be given in the results section.

6.1.5 Run in Period

Prior to the trial at the Queen's Hospital only one of the mattress supplier's product was commonly used. To overcome this potential bias against the second manufacturer it was decided that prior to the study, all staff on the study wards should receive equal training on both types of mattresses. This would be followed by a 1 month unblinded run-in period before the study began to ensure that nursing staff had sufficient knowledge to use the beds with minimal problems.

All pressure sores were being treated following the Burton Hospitals Wound Care Formulary and the Tissue Viability Nurse Specialist's recommendations in conjunction with a protocol defined with Tissue Viability Link Nurses because new products had also been introduced prior to the trial Aquacel, Combiderm and Duoderm.

6.1.6 Aims

- Identify the comparative efficacy of the equipment from the two manufacturers
- Identify the effect of pressure relieving equipment on the length of stay
- Identify whether healing rates may be related to the alternating mattress
- Identify whether there is a connection between nutrition and pressure sores - healing rates?
- Identify patient comfort on the alternating systems
- Identify whether there is a relationship between Hue Saturation and Intensity to pressure sore classification.
- Identify whether HSI correlates with biochemical and nutritional markers
- Identify whether HSI can be used to evaluate pressure sore healing

6.1.7 Pilot

At the start of the run-in period, 4 patients were recruited as per protocol and allocated a mattress. The documentation was tested initially on paper but this was transferred into the Hospital Information Support System with a few refinements. A system of ordering photographs was set up and a few refinements were also required. The pilot patients were photographed digitally with the research nurse present to help position the patient. A protocol was established so that patients would always be in the same position and a standarised photography procedure was also decided upon. e.g. set distance/lighting. Computer software was also tested out in the photography department for transferring images to the computer and then on to the CD ROM. The camera was found to need charging on regular basis and additional PCMIA cards (camera image memory card) were purchased. Gray scales were also tested and refined. Different flash systems were tested in relation to the brightness that was given off and the position to avoid shine reflecting off the patients skin. A training day in Image analysis was provided by Foster & Finlay Associates (software suppliers). A specially created macro was developed for the image analysis to measure wound size and the HSI. The first macro did not have skin tone and this macro was refined later and skin tone added. Data base was designed in Microsoft Access. The data was then analysed to discover if there were any refinements and modifications required in the protocol, and data collection screens and procedure for photography.

6.1.8 Exclusion criteria

- Patient unwilling to participate. Any patient who did not wish to enter the trial was treated according to usual policies, i.e. if the usual policy would have been to offer pressure relief this was provided
- Randomised equipment not available. When a patient was randomised to a bed type, which was unavailable, that patient was

not be entered into the trial and will be treated under usual pressure relief policies. A record of failed admission to the trial was made.

- Readmission of patient with sores who have previously been in the trial. Any patient who had been entered into the trial but required re-admission was excluded from further entry, to prevent accumulation of biases.
- Obesity: patients > 25 stones in weight were not admitted since they required special bed frames.

6.1.9 Patient Eligibility Criteria

- Patients with pressure sores Torrance grade 2 or above.
- Informed consent: included consent to take photographs of all sores and to publish photographs in scientific journals and with permission to allow copies photographs to be given to participating companies provided that no identifying details are included.

6.1.10 Monitoring of Equipment

An equipment log was kept on the internal mailing system and any faults with equipment recorded in connection with following :

1) Failure due to incorrect use (nursing failure).
2) Failure due to equipment malfunction.
3) Failure requiring equipment repair.
4) Failure requiring equipment replacement.
5) Inability to place patient on 'randomised' equipment due to

unavailability.

6) Equipment service not related to equipment failure.

6.1.11 Reflective Diary

A reflective diary was kept to record the problems that occurred whilst setting up and during the trial. Intially there were problems establishing a routine with wards but after a few months a pattern emerged that review's were in the afternoon and new patients in the morning. By the end of the trial we had become part of the ward routine.

6.1.6 Statistical analysis

Data was analysed using Microsoft Excel and Access version 6 1997. The initial analysis of the trial was carried out using parametric and non-parametric statistics. To test the efficacy of the randomisation the mean and standard deviation of the patients Waterlow score, age Burton score and the mean grade of all pressure sores and worst sore were calculated. The categorical data (e.g. heel sores/improvement etc was assessed using the χ^2 test. Other tests were chosen appropriately to the data being examined.

6.1.13 Ethical approval

Ethical approval was sought from South Staffordshire Local Research Ethics Committee (LREC), and was approved as no different interventions were used from normal patient care. Patients were consented to the trial by written consent that was kept in all patient trial folders.

6.2. Results

After 6 months of the trial, 86 patients had been recruited and had completed the trial alive (41 on Cairwave, 45 on Nimbus). At the end of the trial, 112 had completed the trial alive (57 on Cairwave, 55 on Nimbus). Including the patients who had died, increased the recruitment figures to 141 patients (71 on Cairwave, 70 on Nimbus). Additionally, 45 patients were recruited but failed to complete the trial, 41 of these were only photographed once and were discharged too soon for any assessment of improvement to be valid: only 4 withdrew (2 did not like being photographed and 2 could not sleep on the alternating cell beds). Table 6.1 shows the mean (± sd) for age, Waterlow score, Burton score and sore severity on admission (as average severity of all sores recorded or worst grade recorded) according to bed type and broken into two groups comprising those who died and those who did not, and therefore completed the study.

6.2 1 Length of stay

The average length of stay of the patients who did not complete the trial was 5.4 days, compared with lengths of stay for completions of 21.6 days (Cairwave) and 21.7 days (Nimbus) for patients completing alive (range 1 –61 days; Fig. 6.1) and 29.7 days (Cairwave) and 24.3 days (Nimbus) for patients who died.

Table 6.1 Patient Characteristics

Figures quoted are mean (± sd). Statistical significance was tested using student's t-test.

Mattress / Cushion	Admission age	Admission Waterlow score	Admission Burton score	Average Sore Grade on Admission	Worst sore Grade on admission
Patients who completed the study				All Patients	
Nimbus	84.6 (± 6.21)	19.1 (± 4.75)	6.8 (± 5.28)	2.57 (±0.48)	3.17 (±0.81)
Cairwave	83.9 (± 5.91)	18.5 (± 5.23)	6.3 (± 4.49)	2.46 (±0.49)	3.14 (±0.98)
P	Not Significant	Not Significant	Not Significant	Not Significant	Not Significant
Patients who died					
Nimbus	85.8 (± 6.04)	20.1 (± 6.40)	13.8 (± 3.82)		
Cairwave	84.5 (± 6.79)	18.4 (± 4.22)	6.8 (± 3.28)		
P	Not Significant	Not Significant	Not Significant		

Figure 6.1 Length of stay by bed type

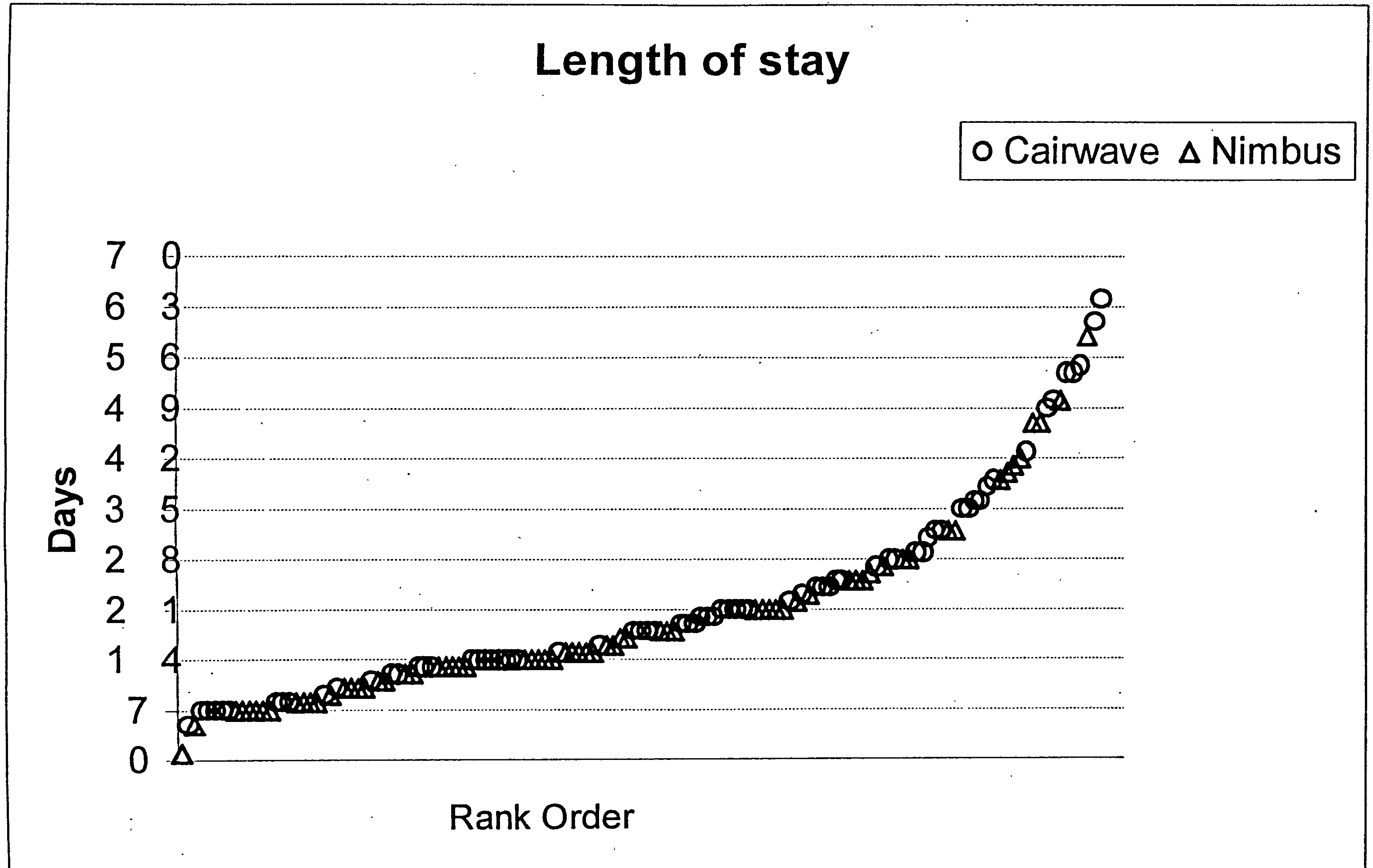


table 6.2 shows the response of pressure sores to treatment using the two types of bed for either patients who completed the trial alive, or for all patients who completed the trial, i.e. including those patients who died. Table 6.2 2a describes overall improvement, Table 2b describes the effect for sacral sores and Tables 2c and 2d describe the response for heel sores. The heel sore response is shown for two time periods, 6 months and final, because for the completed alive group statistical significance was not attained, but the trend suggests that if the trial were lengthened a P value <0.05 would have been achieved.

6.2.3 Comfort

The mean (±sd) comfort scores for each question, and corresponding comments for the relevant range of responses, are shown in table 6.3, broken down by bed type and whether the patient completed the trial or not. All responses were scored so that the lower the value, the better the opinion, and so that the response ranged from 1 = best to 5 = worst. Where a patient made more than one choice of description, the mean score was used. Statistical comparison of comfort data between the two mattress types was only carried out using the data from patients who had completed the trial. Mean comfort score data is shown in table 4 for those patients who withdrew but due to the small numbers, statistical analysis of these patients was not felt to be valid. Since the results came from a restricted

Table 6.2 Ulcer Healing

Table 6.2a. Completed Patients Only: Improvement

	Completed alive		Completed Alive & died	
	Yes	No	Yes	No
Cairwave	52 (91%)	5	65 (91%)	6
Nimbus	53 (96%)	2	65 (93%)	5
χ^2	1.260		0.08	
Significance (P)	0.26		0.78	

Table 6.2b. Completed Patients Only: Sacrum Healed

	Completed alive		Completed Alive & died	
	Yes	No	Yes	No
Cairwave	30 (53%)	27	32 (45%)	39
Nimbus	33 (60%)	22	36 (51%)	34
χ^2	0.62		0.57	
Significance (P)	0.44		0.45	

Table 6.2c. Completed Patients Only: Heels Healed [6 months]

	Completed alive		Completed Alive & died	
	Yes	No	Yes	No
Cairwave	6 (40%)	18	13 (33%)	27
Nimbus	21 (60%)	13	26 (57%)	20
χ^2	3.02		4.98	
Significance (P)	0.082		0.025	

Table 2d. Completed Patients Only: Heels Healed [Final]

	Completed alive		Completed Alive & died	
	Yes	No	Yes	No
Cairwave	17 (39%)	27	19 (33%)	39
Nimbus	24 (59%)	17	30 (55%)	25
χ^2	3.37		5.46	
Significance (P)	0.067		0.019	

Table 6. 3 Comfort Scores: Questions 1a, 1b and 2 refer to mattress comfort and Q3 refers to cushion comfort. The top section of the table shows comfort scores and representative text lines from the visual analogue scale. The mid-section shows mean comfort scores (±standard deviation) and the final row shows the statistical significance as tested using the Wilcoxon and Mann and Whitney Rank Sum method.

	Q1a	Q1b	Q2	N	Q3a	Q3b	N
Cairwave (completed)	1.94 (±0.82)	2.48 (±1.32)	2.81 (±0.96)	29	2.07 (±0.91)	2.85 (±1.37)	17
Nimbus (completed)	1.71 (±0.68)	2.04 (±1.30)	2.46 (±0.92)	24	1.80 (±0.69)	2.13 (±1.31)	16
Significance	P = Not Significant	P = Not Significant	P = Not Significant		P = Not Significant	P = Not Significant	
Cairwave (discontinued)	2.51 (±1.04)	3.50 (±1.69)	3.56 (±1.6)	8	1.94 (±1.05)	2.25 (±1.89)	4
Nimbus (discontinued)	2.33 (±1.81)	2.25 (±1.89)	2.50 (±1.0)	4	1.56 (±0.47)	2.00 (±1.41)	2

Table 6.4 Comfort score interpretation

Score	Question 1a/3a	Question 1b / 3b	Question 2
1	I feel completely relaxed	Very Comfortable	I had my best night ever
	I feel perfectly comfortable	Comfortable	I was quite comfortable
2	I feel quite comfortable	Adequate	I slept alright
	I feel barely comfortable	Uncomfortable	I was a bit uncomfortable
3	I feel restless & fidgety	Very uncomfortable	I had my worst night ever
	I feel cramped		
4	I feel stiff		
	I feel numb (pins & needles)		
5	I feel sore & tender		
	I feel unbearable pain		

ordinal scale, statistical evaluation was carried out non-parametrically using the Wilcoxon and Mann and Whitney Rank Sum test.

6.2.4 Equipment problems

Problems encountered were few. Initially, there were some problems with the welds in the Aura cushion: This had only just been released for trial and all problems were solved after the first month. Two Nimbus mattresses and 10 Aura seat cushions and 7 Cairwave therapy systems and 6 proactive cushions required repair. Otherwise, all mattresses and cushions were routinely serviced after 1 year.

6.2.5 Incidence monitoring

Routine hospital incidence monitoring was carried out during the trial. Before the trial 0.2% of patients developed hospital-acquired pressure sores (Torrance grade 2+). During the trial, the incidence dropped to 0.13%. This was attributed to improved education, vigilance and improved equipment availability.

6.3 Discussion

The project assumed an average length of stay of 18 days and 100% occupancy for the trial equipment (14 beds in all). Thus, we believed each bed should be occupied by 20 patients / year, giving a total throughput of 280 patients in a year, making the planned group size of 100 feasible. After the first 6 months of the trial, it had proven impossible to maintain 100% occupancy because of wide variation in peak and trough requirements; and a number of seriously ill patients had occupied trial beds for considerably longer than was expected which made the average length of stay approx. 22 days. The death rate was also significantly greater than expected. Consequently, the available data was statistically examined after 11 months to determine whether the trial should be extended by TR but no information allowing the companies or the nurses running the trial to identify the more effective bed was released. It was found that both mattresses were equally efficient at resulting in general improvement and at healing sacral sores and that it would be extremely unlikely that there would ever be any statistically demonstrable difference between the two mattresses, but there was a statistically significant superiority for the Nimbus mattress in respect of heel sore healing when all patients who had completed the trial (live exit and dead) were examined. The numbers in the completed alive group however were insufficient and it was estimated that if trial was extended by 6 months, a statistically significant number of patients could be discharged alive. Despite this extension, it proved impossible to recruit sufficient patients to attain significance and the trial was terminated at 18 months.

After 18 months of data collection, it was found that there were again no statistically significant differences between the mattresses when overall improvement and sacral sore healing were considered. For heel sore healing however, the difference between the beds for all patients remained statistically significant and the trend of results and P values is suggestive that a further extension would have resulted in a statistical significance being demonstrated for the 'discharged alive' sub-group rather than being demonstrated only for the entire patient sample. This implies that the special heel pressure reduction system of the Nimbus mattress may be effective at inducing healing.

6.3.1 Comparability of patient groups

One possible explanation for the differences found would be that the randomisation procedure had failed and all of the more severely ill patients had been placed on the bed which appeared to perform least well. To fully answer this question requires the completion of the image analysis phase of the project, which will look at healing rates specific to different severity grades of sores. Initially, it is only practical to examine the baseline patient data in terms of age, Waterlow score, Burton nutrition score and severity of sore on admission to the trial. Table 6.1 shows that there were no significant differences between the patient groups.

6.3.2 Length of stay

There is little that can be said about length of stay. Essentially, this was dictated by the medical condition of the patients. Figure 6.1 shows that there was a continuum of stays and that the trial did not have a major effect on delaying discharge. Since photographs were taken weekly, a trial effect would have resulted in clustering of lengths of stay in multiples of 7 days. This is not seen. The average length of stay is therefore likely to be a true estimate of the time required to treat pressure sores / the patient's presenting complaint.

6.3.3 Comfort

There is little in the nursing literature dealing specifically with comfort of pressure relieving systems. The prime reason for this may be that comfort is very subjective and individual: what pleases one patient may pain another. Several small clinical trials have assessed comfort but often data has been collected by nurses who have their own perceptions of whether a bed is comfortable or not. Furthermore, assessments of comfort have often been made after only relatively short periods of time, before the patient has become used to the bed's characteristics, or no indication of the delay before survey has been given. We used a visual analogue scale as described by Gray et al (1994) who assessed the comfort of Softfoam mattresses when new, versus Linknurse mattresses, and 3 years later Gray et al (1997), alone because the Linknurse mattresses had degraded to uselessness. In our study, comfort data was collected by the Clinical Audit department, and the auditor had no understanding of the different types of bed, and could therefore not exhibit bias. We found that there was no statistically significant differences between the two mattresses on test.

In summary therefore, we have demonstrated that both the Nimbus mattress and Cairwave therapy systems are effective treatments for pressure sores but since no placebo group was used, it is not possible to determine whether patients would have developed more pressure sores if they had remained on a standard mattress. Both mattress / cushion combinations provided an overall improvement in more than 90% of patients and healing of approximately 50% of sacral sores. However, we have shown that the Nimbus mattress is significantly more effective for treatment of heel sores (55% healing) than the Cairwave therapy system (33% healing) [in line with the 20% difference chosen in the power calculation]. The precise significance of this to the NHS is not clear. The average length of stay on either bed was approximately 21.5 days and therefore it appears that presence or absence of a sore did not affect the discharge of the patient. Furthermore, there was no clear difference between the mattresses or cushions for comfort scores. Therefore, other factors not covered in this paper may be more important when choosing which mattress should be used: purchase price, equipment failure rates, nursing interventions required (e.g. frequency of patient turning), etc.

6.4 Conclusion

- **The NHS spends very large amounts of money on pressure sore prevention / treatment but has no 'quality' evidence on which to base purchasing decisions**
- **Significant differences in the performance of pressure relieving equipment can be demonstrated. This may not affect length of stay and therefore other factors such as nursing interventions required, ease of equipment use, and equipment cost are likely to be more important when making equipment choices.**
- **Randomised trials to produce the required evidence are possible but need considerable input of resources because there is significant 'wastage' of recruits into trials in the necessary patient group.**
- **Improved availability of pressure relieving equipment can reduce overall hospital incidence of pressure sores.**

Chapter 7

A Comparison of healing rates on two pressure-relieving systems

Chapter 7

A Comparison of healing rates on two pressure-relieving systems

The second study reported in this thesis a more detailed analysis of the 141 patients assessed using computerised image analysis of the digital images of sacral ulcers captured during the trial. Healing rates were specifically discussed as well as other patient characteristics. Ninety-eight percent of ulcers examined were deemed superficial (Torrance grade 2a / 2b / 3). Precision of image analysis assessed by within- and between-batch Coefficients of Variation was excellent: Calibration CV 0.93 - 1.84%; Area CV 4.61 - 5.72%. The healing rates on the two mattresses were not shown to be statistically different from each other.

7.1 Background

Approximately 70 % of all pressure ulcers develop in hospital (Dealey 1994). Furthermore, at any one time, around 50 % of patients are at risk of developing pressure ulcers (Audit Commission, 1985). Recent estimates of the cost of pressure ulcers to the NHS are more than £320 million (Audit Commission, 1985), or £400-1000million (Moody, 1997) per annum. The Department of Health (DoH) states that prevalence of pressure ulcers is an excellent indication of quality of care (DoH, 1993) but the equipment needed to prevent hospital acquired pressure ulcers is expensive and often in short supply. To reduce the incidence of ulcers within available equipment constraints, *an evidence-based pressure ulcer prevention policy* was introduced and in the process it was discovered that despite the wide variety of pressure relief equipment on the market, the few clinical trials that have taken place have all been small and unable to produce the statistical evidence of efficacy or cost-benefit analyses required to found an evidence-based policy (Swain et al, 1992; Hitch, 1994).

The preliminary results of a randomised-controlled trial comparing the relative efficacy of two pressure-relieving systems: Huntleigh Nimbus 3 & Aura Cushion and Pegasus Cairwave Therapy System & ProActive Seating Cushion has been reported in chapter 6 (Russell et al, 2000). Although both mattresses were effective treatments for pressure ulcers, the Huntleigh equipment was demonstrated to be statistically significantly more effective for heel ulcers but no differences were demonstrated for sacral ulcers. The Nimbus 3 mattress had the heels cells modified prior to the commencement of the trial and Cairwave was not modified. Detailed computerised image analysis was not undertaken during the first paper only improvement of ulcers and other patient characteristics.

Traditionally, wound area has been measured two-dimensionally by multiplying its length and width (see chapter 5 for more detail). This assumes wounds are rectilinear (i.e. oblong). This assumption can give an estimate significantly at variance to the true area. Alternatives include tracing the wound on acetate, cutting out the resultant shape and weighing, sophisticated photography with planimetry or computer analysis of images, or tracings

(Brohannan and Pfaller, 1983; Anthony, 1987; Majeske, 1992; Ahronic et al, 1993). Cameras have even been linked directly to computers to provide reproducible results (Palmer et al, 1989). All wound area measurement techniques have their disadvantages; tracing can be time-consuming, planimetry can be slow and expensive and computer image analysis can suffer inter-observer variability, e.g. due to individual edge detection criteria (Anthony, 1987). Ruler methods (e.g. the Kudin ruler (Kudin, 1985)) have been shown to underestimate wound area, in some cases by orders of magnitude (Plassmann, 1995). Additionally, the variability of ruler estimates is high. Since in a research project reproducibility of measurement is paramount, we used an image-based protocol. Photographic methods have been validated against acetate tracing (Thomas and Wysocki, 1990), which has been shown to be superior to ruler-based methods.

One of the major problems with trying to measure a wound is the natural curvature of the body as all the tools are designed to measure wounds as a flat object and consequently will be inaccurate (Melhuish and Plassmann, 1994; Plassmann, 1995; Bates-Jensen, 1995). Furthermore, a camera angle of 20° to the perpendicular can result in a reduction of the measured area by approximately 10% (Palmer et al, 1989). Given standardisation of image recording, computer analysis allows reproducible measurement of wounds. It is more reliable than manual measurements: 25% between-observer coefficient of variance (CV) for repeat estimations carried out manually compared with 0.2% for computer analysis (Mekkes and Westerhof, 1992). Taylor studied various shape, i.e. circles, rectangles, polygons, traced by a computer program with five volunteers, 3 male, 2 female, 4 right-handed and 1 left-handed (Taylor, 1995 and 1997). A mouse was used to trace image's outline, which was then stored analysed by the computer. The results demonstrated that an inter-observer CV of 1.3 - 2.0% is achievable (Taylor, 1995 and 1997).

Data suggest that measurements of an ulcer's dimensions, exudate and tissue reaction (granulation /necrosis etc.) provide valid indicators for monitoring changes over a time period. A study of 14 patients, 7 with pilonidal sinus excision and 7 with abdominal wound cavities after surgical procedures has been reported (Melhuish and Plassmann, 1994): Wounds were evaluated at weekly intervals using light measurements for the area, volume and depth. The wound edges were highlighted with a mouse, and the computer calculated the number of pixels in the area being studied. Results demonstrated a correlation between volume and circumference assessed using the Gilman formula (Gilman, 1990). The authors noted difficulty in reproducible measurement of area and volume due to the wound locations. However, they were able to conclude that, it is acceptable to monitor progress by assessing the wound circumference.

7.2 Hypotheses

To test if pressure ulcers can be measured with precision and accuracy using image analysis?

To compare healing rates of the two alternating mattresses?

7.3.Method

Data were analysed from the randomised control clinical trial of Pegasus Cairwave and proactive seating cushion and the Huntleigh Nimbus 3 & Aura seating cushion for the treatment of pressure ulcers (Russell et al, 2000). The trial collected data on 141 patients over 18 months. The entry criterion for the trial was presence of a pressure ulcer, Torrance grade 2 or greater (Torrance, 1983). All sacral ulcers were photographed digitally at weekly intervals. The recruitment, randomisation, monitoring other trial procedures and preliminary results have been previously reported and will not be further detailed here.

7.3.1 Digital Images

All sacral ulcers in the trial were photographed, heel ulcers were counted but not recorded because heels are a curved surface and reproducible images were found to be impossible to achieve. Images were recorded using a Kodak 410 Digital Camera system and were recorded as a 32-bit, 1524 x 1012 Pixel data. A standard L-shaped white scale with centimeter markings framed all ulcers. Digital imaging was used because, no film was involved, preventing loss of data during postal processing, preventing variability in image colour due to film & chemical lot variation, and scanning inaccuracies. To ensure reproducibility, we took standardised digital images; i.e. the patient lay on the same side (left or right) and in the same position, the surroundings and lighting were the same for each image, and the camera was always positioned carefully. Uncompressed files were saved to camera, uploaded and white balance corrected colour against the scale using image acquisition software PhotoShop Plugin (Kodak, Rochester, USA) and Adobe PhotoShop version 5.0 (Adobe Systems Inc., USA) to remove lighting effect variation, and copied to CD for permanent storage. To ensure accurate length calibration, any rotation of the image was corrected to ensure the scale lay parallel to the frame.

7.3.2 Image Analysis

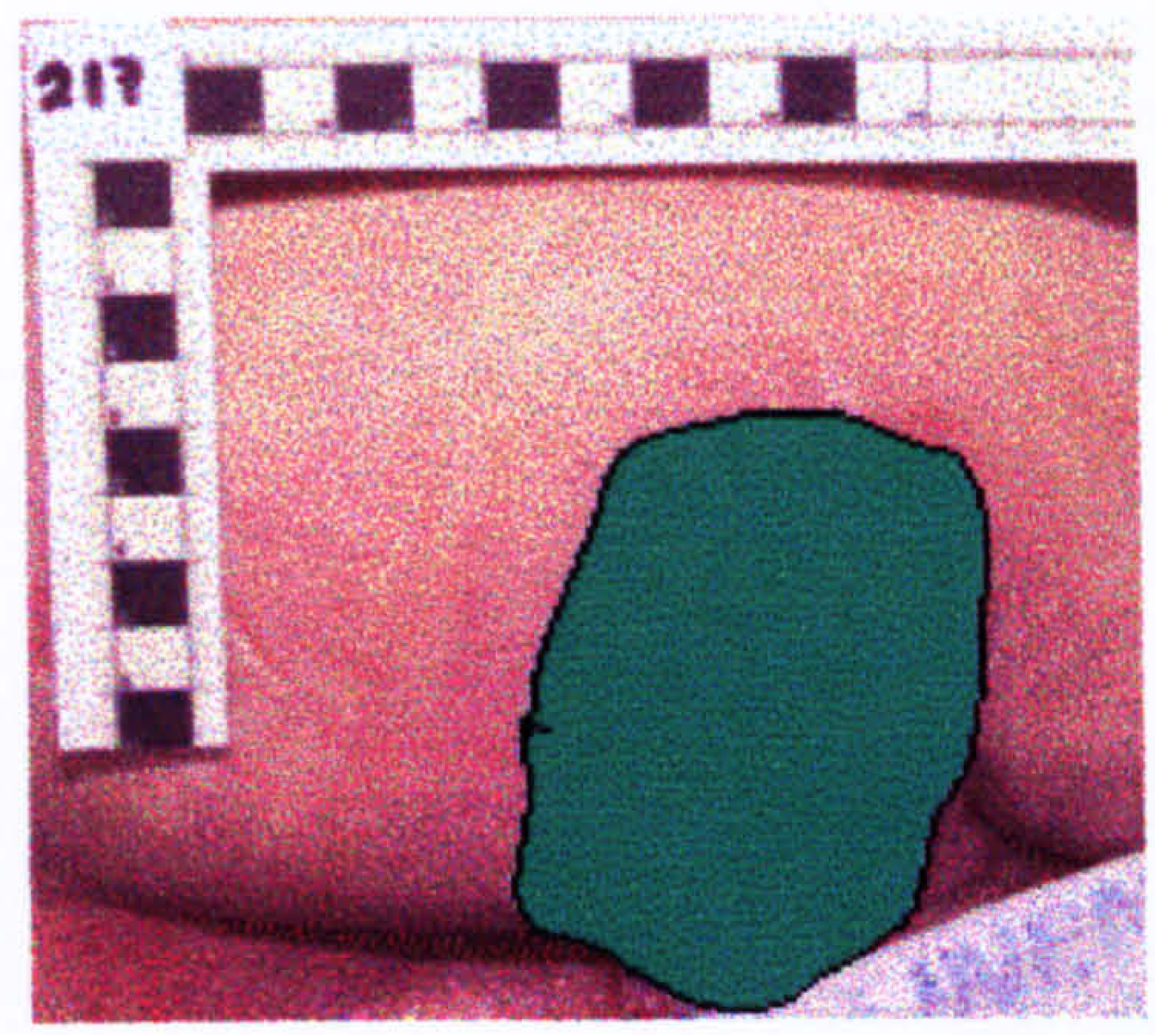
This study analysed only the sacral ulcers occurring during the trial. Digital images were analysed using PC Image software (Foster and Findlay Associates, Newcastle-on-Tyne) using a 'macro' which automatically assessed the ulcer length & breadth, area, and colour (Hue, Saturation & Intensity). A macro is a recorded sequence of commands that are collected together and run as a single instruction. Stage 1 was calibration against the length scale. Stage 2 was identification by manual out-lining of small ulcer areas and total ulcer area and a normal skin area with the mouse. Stage 3 was automatic assessment of for each identified site of the area, location relative to the origin, and colour. Finally all data was imported into a database. All individual measurements for each sacral ulcer area were then manually coded (S1, S2, S3... etc.) by comparing the location (X, Y coordinate data) with a printed photograph so that longitudinal changes in wound area could be tracked.

7.3.3 Precision of Computerised Analysis

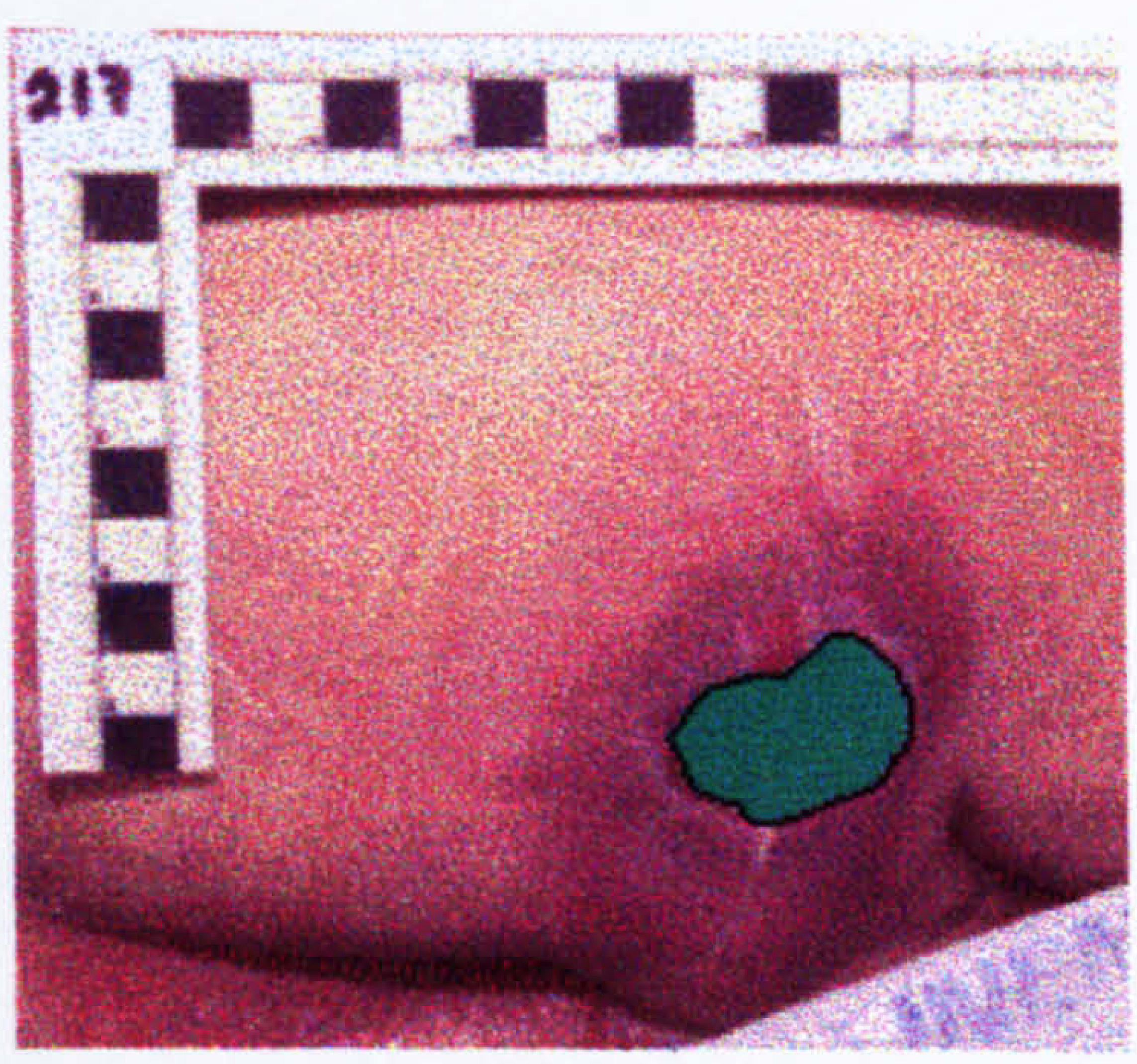
Analysis precision was assessed by repeated analysis of 2 set images using standard techniques used to assesed laboratory imprecision (Kringle and Johnson, 1987). To assess within-batch precision repetitions were made in a single analysis session and to assessed between-batch precision, 3 test images were analysed every time a new analysis session was completed.

Figure 7.1 Procedure for Wound Area Measurement

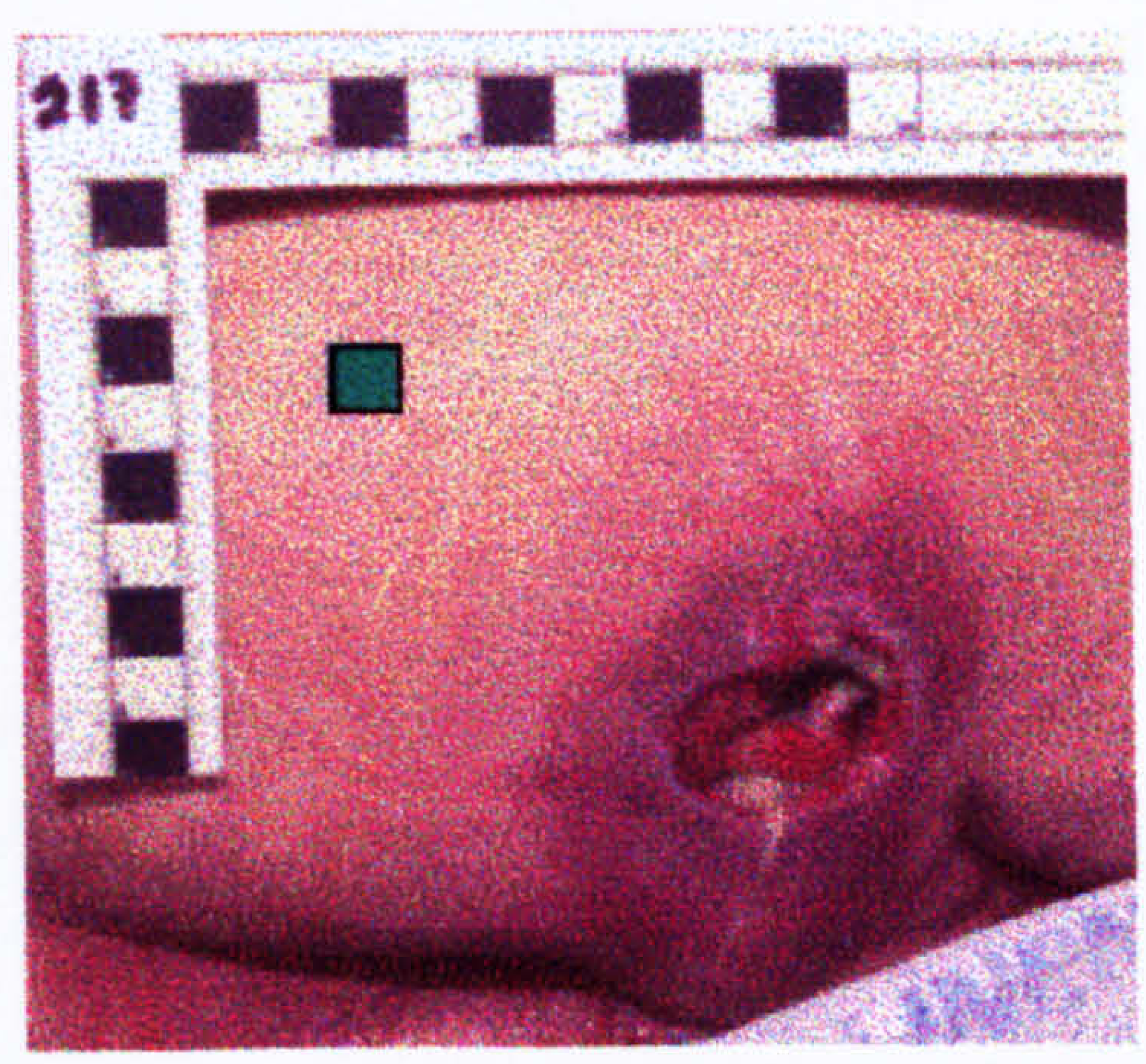
1) Select Image & Calibrate
By drawing a 4cm line



2) Manually outline erythema
using mouse



3) Manually outline ulcer
using mouse



4) Select area for skin tone
measurement

7.3.4 Analysis of Healing Rates

Analysis of wound healing rates in clinical trials is challenging: depending on the method used for analysis it is possible to conclude that wound A heals faster than wound B, heals at the same rate or heals slower! (Gorin et al, 1997). Since healing assessed by total area healed or percent area healed can be adversely influenced by the initial wound area and wounds tend to heal inwards from the outer edge, we utilised the linear growth of wound edge method suggested by Gorin.

We made one alteration in that wound margin length is a fractal dimension: i.e. as one increases the precision of definition of the wound edge, the length continues to increase e.g. if the distance around an island can be measured as 1 mile, this can be increased by taking the measurement into every inlet and bay, and then around every rock - meaning that the true distance is actually impossible to assess. Consequently, we measured the area of each wound and assumed that the wound was a perfect circle: by applying the formulae for the area of a circle (πr^2) the radius could be determined and then the formula for the circumference of a circle ($2\pi r$), the estimated linear wound margin was obtained. Incremental (7-day) and total wound area changes for each identified wound ($\Delta A = A_{initial} - A_{next}$) were calculated and the linear daily wound edge growth was calculated thus:

$$Wound\_Progression = \frac{\frac{\Delta A}{Circumference}}{TimeIncrement}$$

The calculation for wound progression gives a negative number for a reduction in wound area (healing) and a positive number for increase in wound area. Values are reported in mm/24 hours.

7.3.5 Analysis of Confounding Medical Conditions

To determine whether there were any significant differences in the patients randomised to each group which may have affected healing rates (e.g. if one group failed to heal, was this because they were more incontinent), the medical conditions of patients admitted to the trial were evaluated. Specifically, we classified the reasons for admission into 7 categories (Table 1) and compared the distribution of patients on each surface by χ^2 test. Similarly, continence status, mental status and nutritional status were also compared by χ^2 test (Table 7.1).

7.4 Results

7.4.1 Patient Characteristics

Table 7.1 shows the basic medical conditions resulting in admission to hospital. Table 7.2 shows frequency of incontinence status, mental status, and nutritional status. χ^2 testing was used to compare the frequencies within each category with the null hypothesis that frequencies were similar in both groups. No statistically significant differences were demonstrable for reason for admission, mental status or nutrition state. Furthermore, admission type (emergency / GP / other), bed frame (mesh / ridged / solid), frequency of nurse repositioning patients on the mattress, all showed no significant differences (raw data not shown). Repositioning was shown to have been carried out every 4 hours despite advice from mattress suppliers that longer intervals may be acceptable for some patients: turning frequencies are not specifically recommended as patients may need turning for reasons other than pressure area care.

A statistically significant difference was shown for incontinence. This demonstrated that there was a significant difference between patients on Nimbus and Cairwave equipment. A greater proportion of patients on the Nimbus bed were incontinent of either faeces or urine

7.4.2 Precision of Image Analysis

Precision estimates are shown for within and between batch image processing. For within-batch precision, estimates for 2 different images and for between-batch precision, estimates of precision for 3 images are shown.

Within-batch precision Coefficients of Variation

Calibration: 1.17% and 0.93%

Ulcer Area determination: 4.77% and 5.53%

Between-batch precision Coefficients of Variation:

Calibration: 1.04%, 1.42% and 1.84%

Ulcer Area determination: 4.71%, 5.43% and 5.72%

The coefficient of variation allows an estimate of how likely the value measured is to be the 'correct' result. For example, if the CV is 1%, then there is a 73% probability that the measurement made will be within 1% of the true value and a 95% probability that the result is within 2% of the true value.

Table 7.1
Medical conditions causing admission to hospital.
$\chi 2 = 1.96$; $P = 0.92$ (not significant)

	Cairwave	Nimbus 3
Malignancy / terminal care	7	8
Cardiovascular	14	9
Cerebrovascular / Dementia	8	10
Infection	13	17
Orthopaedic	12	11
Wound Care	10	10
Other Medical	13	14

Table 7.2
Nursing assessments of incontinence, mental state and nutritional status.

	Cairwave	Nimbus 3
Incontinence of urine	5	15
Urinary Catheter	21	13
Incontinent of faeces & urine	11	15
Not Incontinent	37	27
$\chi^2 = 9.005$: $P < 0.05$		
Mental status - unknown	2	4
Disorientated	15	24
Confused	7	3
Lucid	47	37
Poor Memory	3	1
$\chi^2 = 5.82$: P = Not Significant		
Nutritional status - unknown	1	2
Fair	37	34
Good	14	9
On Fluids only	5	5
Reduced intake	17	19
$\chi^2 = 1.79$: P = Not Significant		

7.4.3 Analysis of Ulcer Grades at Entry and During Trial

It must be noted that in the preliminary report of this study (Russell et al, 2000), it was stated that 30 (of 57) patients on Huntleigh Nimbus equipment and 33 (of 55) on Pegasus Cairwave equipment had sacral ulcers, 'completed' the trial alive, and demonstrated improvement in their sacral ulcers - the remainder of these groups did not improve. Table 7.3 shows the total number of different ulcers of each grade (Torrance, 1983) at entry to the trial and the total number different of ulcers of each grade noted during the trial, for all patients and all ulcers which could be photographed twice (i.e. present at least 7 days). This definition included patients who died and therefore had not 'completed' the previous trial. There was no statistically significant difference in the numbers of patients who died on either mattress. Consequently there were a greater number of patients; comprising 74 Pegasus Cairwave patients and 59 Huntleigh Nimbus patients whose sores were evaluated to determine their healing rates. If a patient had 2 ulcer areas, this counted as 2 separate ulcers, which explains the considerably higher numbers of ulcer in this report than reported in chapter 6 (Russell et al, 2000).

For the purposes of our analysis, we divided Torrance Grade 2 into grade 2a and grade 2b, such that grade 2a represents areas of persistent erythema with intact epidermis and grade 2b is areas of persistent erythema with epidermal loss (Nixon et al, 1998). The total number of ulcer areas / patient at entry and in total are shown in table 3. We have also evaluated the total number of sores at entry to the trial and the total number of ulcers ever present to determine

Table 7.3
Incidence and size of ulcers at entry to trial, and of all ulcers that were present long enough to have 2 photographs (i.e. a minimum of 7 days).

	Cairwave (@ trial entry)	Cairwave (All ulcers)	Nimbus (@ trial entry)	Nimbus (All ulcers)
Grade 2a	74	71	55	59
Grade 2b	77	107	52	73
Grade 3	7	10	0	1
Grade 4	1	1	3	3
Grade 5	0	0	1	1
TOTAL Ulcers	138	189	111	137
Total Patients	74	74	59	59
Ulcers / patient	2.15	2.95	1.88	2.305
Median Area of Grade 2a ulcers (cm^2)	48.1	45.7	50.5	43.2
Mean Area of Grade 2a ulcers (cm^2)	58.5 ± 55.5	58.1 ± 71.7	73.4 ± 72.7	50.5 ± 39.8
Median Area of Grade 2b ulcers (cm^2)	0.27	0.27	0.20	0.27
Mean Area of Grade 2b ulcers (cm^2)	0.77 ± 1.15	0.72 ± 0.97	0.57 ± 1.01	0.57 ± 0.91

whether there was any bias in recruitment or difference in the performance of the mattresses tested. The distribution of ulcer types was not significantly different at entry or later in the trial by χ^2 test (P>0.05).

In Table 7.3, it is also evident that the total number of ulcers increased in both groups (at grade 2 especially) and that there appeared to a greater proportion of patients who developed more grade 2b ulcers on Pegasus Cairwave equipment. It was possible that this development of larger number of ulcers is due to a greater number of 'smaller ulcers'. The image analysis software interprets the creation of ulcerated islands surrounded by non-ulcerated tissue developing as part of the healing process as new ulcers – i.e. a single area of grade 2b could be separated into 2 areas of grade 2b by development of an epithelial bridge which would then be called 2 ulcers. Therefore, the median & mean area of ulcers at first appearance and on trial entry, for ulcer grades 2a and 2b, are shown. In addition, the total and mean sore areas per patient were also examined (data not shown) and showed similar results. Overall, the 'at entry' data shows that there is no statistically significant difference between the area of grade 2a sores on the Huntleigh Nimbus and on the Pegasus Cairwave. When all ulcers are considered, the mean area on the Pegasus Cairwave remains similar but that on the Huntleigh Nimbus decreases. Again, this is not statistically significant.

7.4.4 Analysis of Wound Progression Rates

Figure 7.1 shows graphically, and Table 7.4 shows numerically the sacral ulcer healing rates for grades 2a and 2b, with grade based on the first time a ulcer was assessed, with mean and standard deviation determined from data trimmed to exclude gross outliers. No statistically significant difference between the distributions of healing rates for grades 2a or 2b were shown by Wilcoxon rank sum testing.

7.4.5 Length of Stay

The overall mean (±sd) and median lengths of stay for patients with sacral ulcers, completing the trial were 25.3 ± 15.9 days, median 20 days (Pegasus Cairwave) and 23.3 ± 21.7 days, median 17.5 days (Huntleigh Nimbus). The difference between the lengths of stay was tested by student's t-test and by Wilcoxon rank sum test and no statistically significant differences were demonstrable. Similarly, separately analysing the patients with grade 2a ulcers of grade 2b ulcers identified no statistically significant differences..

7.4.6 Cost Effectiveness Analysis

No formal cost effectiveness data is available, but there was no difference between either mattress in respect of the perceived nursing interventions required, dressings applied, length of stay, etc. Consequently the only factors

Figure 7.2 Healing Rates

affecting comparative cost-effectiveness were the purchase / rental costs and energy consumption of the equipment.

7.5 Discussion

In our primary study chapter 6 (Russell et al, 2000), we reported that the patients on each mattress type were broadly similar, in terms of age, Waterlow score, Burton score (Russell et al, 1998), average and highest grade of ulcer present on admission to trial, and length of stay. This study reports that there were no biases in terms of clinical reason for admission, mental state, or nutritional status (tables 7.1 & 7 2). There is however, one area where a significant difference was demonstrated: incontinence. Significantly fewer patients on the Huntleigh Nimbus equipment were continent than those on Pegasus Cairwave equipment. These conditions would be expected to result in a greater incidence of pressure ulcers (chapter 6 Russell et al, 2000), but no significant trend was demonstrable.

The wound healing rates (Table 7.4) are interesting because the mean indicates that there is actually progression rather than regression, whilst the median indicates regression. This is the classic presentation of a skewed distribution in which despite trimming of gross outliers, a small number of poor results can give a false impression of the overall picture. Figure 7.1 makes this more clear because one gets the clear impression that both mattresses overall promote healing of grade 2a ulcers [as proven by the median healing rates]. The similarity of lack of progression or regression for

Table 7.4
Statistical values describing healing rates on the two systems, by grade of pressure ulcer; see also figure 1. Grades 3 and above excluded due to insufficient data. Values shown are wound margin movement in mm/24 hr. A negative value indicates reduction in wound area (healing), a positive value indicates wound area increase.
NOTE: No. of ulcers in this table differs from No. of ulcers in table 3 due to trimming of outliers.

	Cairwave		Nimbus	
	Grade 2a	Grade 2b	Grade 2a	Grade 2b
No. of ulcers	77	104	72	73
Mean	0.17	- 0.84	1.50	0.04
SD	1.72	1.07	1.22	2.18
5%ile	- 1.97	- 0.72	- 2.39	- 0.37
Median	- 0.17	- 0.02	- 0.29	0.015
95%ile	3.73	1.48	2.89	1.45

grades 2b is also evident from the graph. Graphically, it is obvious to the eye that the statistical proof of no significant difference between healing rates on either mattress is correct.

We express confidence in our results because the precision of analysis was shown to be extremely good. In Clinical chemistry circles, analytical imprecision has long been considered important. In 1973 it was recommended that the maximum imprecision allowable for any assay in clinical use should be an between-batch Coefficient of Variation (CV) of 10% (Tonks, 1973) and further it was specified that any CV greater than 20% was medically useless (Elion-Gerritzen, 1980; Skendzel and Barnet, 1985). The meaning of a CV is explained in the results section. Since we were researching the effect of treatment we wished to evaluate small changes as precisely as possible. Computer image analysis therefore proved itself to be extremely effective, as the CV for wound area was no greater than 7%. Thus, our maximum 95% confidence limit for any measurement was 1.97 x 7%, or approximately ± 12%: a figure far better than would have been achieved by the 2-D rectilinear approximation method.

The reproducibility of our findings is important because it provides good confidence that the lack of clinically significant difference between the two systems is genuine and not due to random error introduced during analysis. Therefore, our results allow an estimate of the comparative cost-effectiveness of the two systems to be made. In informal surveys of nurses on the trial wards, we found no differences in the perceived nursing interventions required, nurse time required, dressings applied or equipment breakdown frequency. As stated above, there were no differences in length of stay despite the apparently greater tendency for patients on Pegasus Cairwave equipment to develop extra sacral ulcers, indicating that in our study, the development of sacral ulcers is not a primary cost-driver.

In the planning stage of the clinical trial, 80% power to detect a 10% difference was projected. Due to recruitment difficulties, the final study had 80% power to demonstrate a 20% difference between the two mattresses. It is clear from our results that no difference of this magnitude was found. The results do not prove that there is no difference between the mattresses. They do however show that it is highly unlikely that a difference of more than 20% in performance exists.

In the absence of formal cost-economic analysis, we identified that the main influences on cost-effectiveness of mattress systems are the length of stay, nursing interventions, wound dressings applied and equipment costs. We could identify no differences in length of stay, nursing intervention or dressings. Therefore, the purchase / rental cost, and energy consumption costs are the only differences between the two mattress systems, which at the time the trial was carried out, were marketed for patients at comparable risk / needing similar treatment. Hopefully the data presented here will assist in the rational choice of pressure-relieving equipment.

Chapter 8

How Accurate are Pressure Ulcer Grades?

An image-based survey of nurse performance

Chapter 8
How Accurate are Pressure Ulcer Grades? An image-based survey of nurse performance

My third study was a descriptive study using a questionnaire and twelve digital photographs classified by a consensus panel of experts using the European Pressure Ulcer Advisory Panel and Stirling plus digits classifications. The expert panel comprised of 5 tissue viability specialists / clinical lecturers in tissue viability with many years of collective experience and examined 30 images over 2 ½ hours. In general consensus on wound grading was good with little argument. In only 2 images was there insoluble disagreement. Two hundred subjects were recruited from a Tissue Viability Society (N = 50), European Pressure Ulcer Advisory Panel (N=50), five Community Trusts (N=50) and five Acute Trust (N=50) in the England and Wales. The subjects were asked for demographic details (qualifications achieved, number of years qualified, employment grade and how their knowledge of classification of pressure ulcers has been obtained. The second part of the questionnaire asked them to classify twelve digital photographs of pressure ulcers against the European Pressure Ulcer Advisory Panel (EPUAP) and the Stirling plus digits.

8.1 Background

There are approximately 16 published pressure ulcer classification systems of which 6 are in routine use (Heenan 1994, Healey 1996). The main area of conformity of all classification scales is that higher numbers denote more severe grades of pressure ulcer. A particular dilemma for the practitioner is not being able to recognise a pressure ulcer in its early stage and how deep this tissue damage is. It has been proposed that failure to detect pressure ulcers in the early stages may be due to a lack of clarity on how to use grading systems (Reid 1994, Healey 1996). Other variables may also be responsible. There has been very little research into nurses' understanding of the classification of pressure ulcers.

Healey (1995) carried out a similar study to the one reported here and examined Stirling digit 1, Torrance and Surrey grading of 10 photographs of pressure ulcers of Caucasian patients: Each pressure ulcer was graded against the Surrey, Torrance and Stirling Classification systems. The least complex grading system was preferred by the nurses surveyed - 57%, 16% and 11% Surrey, Torrance, and Stirling respectively. The level of agreement found was Surrey - 67%, Torrance - 60% and Stirling - 39%.

Buntinx et al (1995) conducted a small study of inter-observer variation in assessment of skin ulcers. Three nurses and three physicians, with chronic wound experience, studied twenty-seven skin ulcers using five classification systems to evaluate reliability and validity. It was found that inter-observer reliability was poor and further study was recommended.

Essentially, previous studies have demonstrated poor agreement between grading systems but were either small or relied on a single observer to determine what the 'correct' answer should be. We repeated the previous studies using a set of photographs graded by consensus, but acknowledge the difficulties of grading from images. In addition, we evaluated the current levels of education and attitudes to further education of different groups of nurses in the hope that this may prove useful for health service planning in the future. To our knowledge no previous examination of nurse education in respect of pressure ulcer classification has been published.

8.1.1 Precision and Accuracy

Assessment of a pressure ulcer grade results in a number and just as we expect a serum sodium to be 'correct', it is reasonable to expect pressure ulcer grading to be 'correct'. But what is a 'correct' result? Essentially, this is a result in which we can be confident. To achieve this, a result must be reproducible and have a constant meaning. This is usually monitored in pathology laboratories by examination of precision and accuracy. These are illustrated by the 'archer' analogy (Figure 8.1).

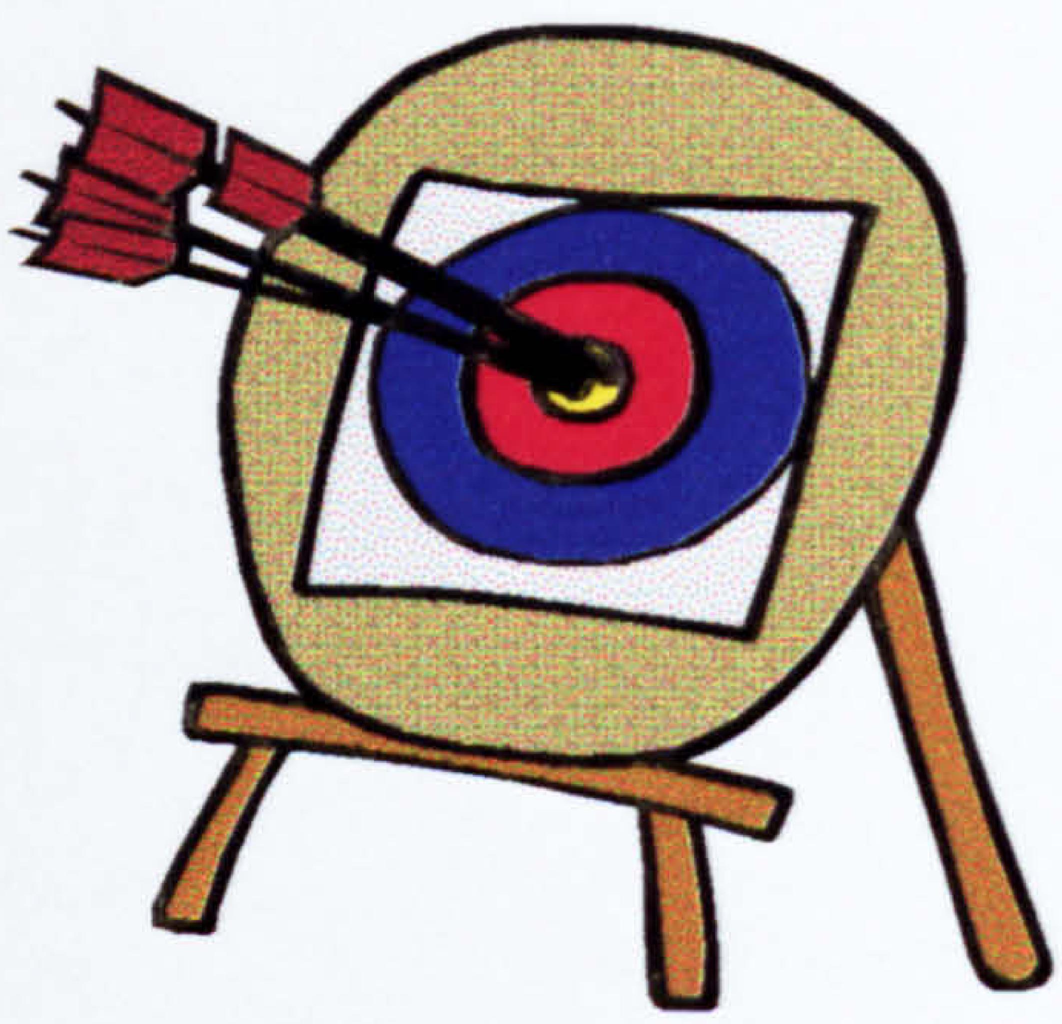
8.2 Methods

8.2.1Consensus Panel

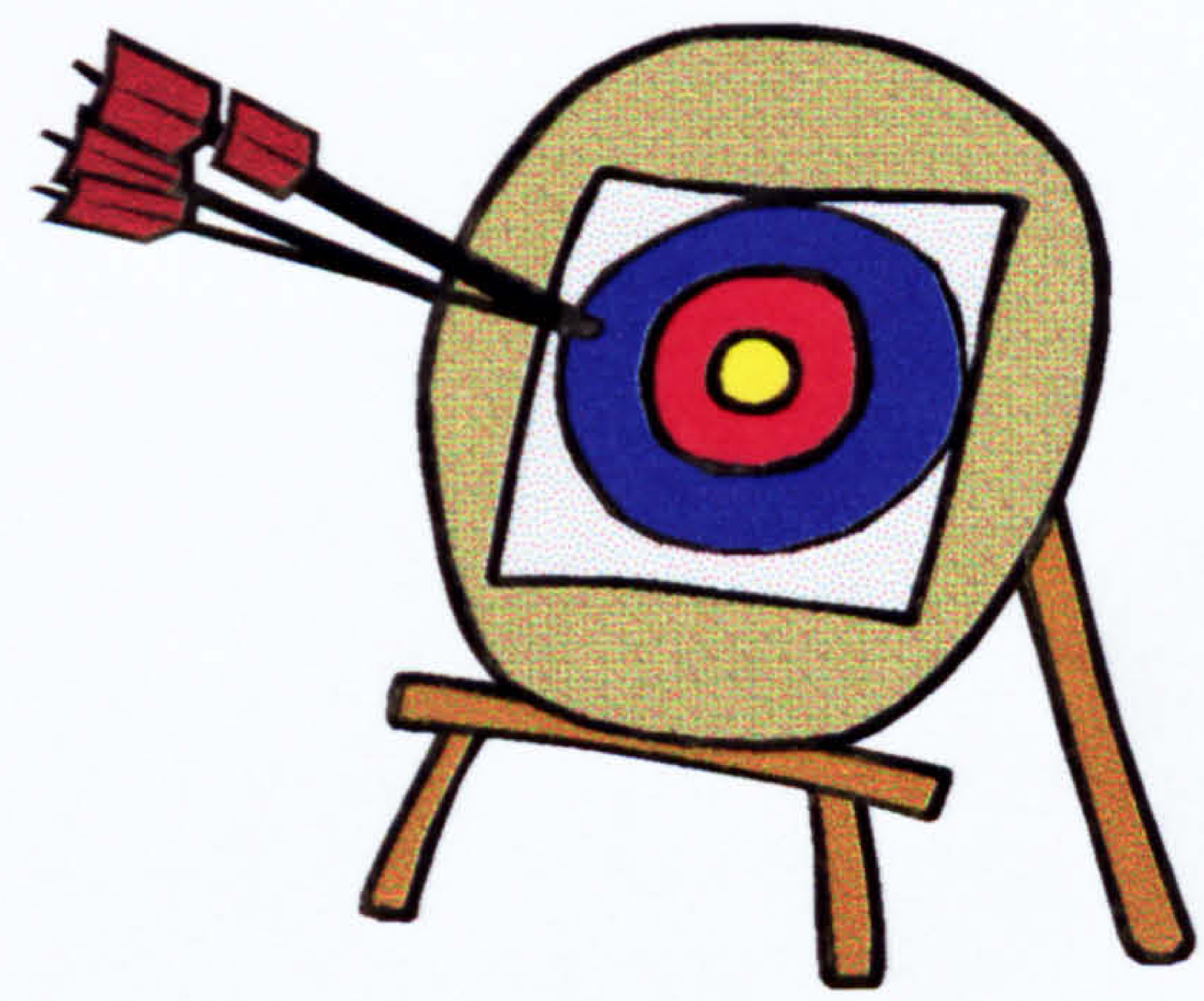
A consensus panel of experts examined 30 digital photographs and classified the images of pressure ulcers using the European Pressure Ulcer Advisory Panel and Stirling plus digits classifications. The expert panel comprised 5 tissue viability specialists / clinical lecturers in tissue viability with many years of collective experience. The panel examined the 30 images over 2 ½ hours. In general, consensus on wound grading was good with little argument. In only 2 cases was there insoluble disagreement.

Figure 8.1 **Precision and accuracy- the archer analogy**

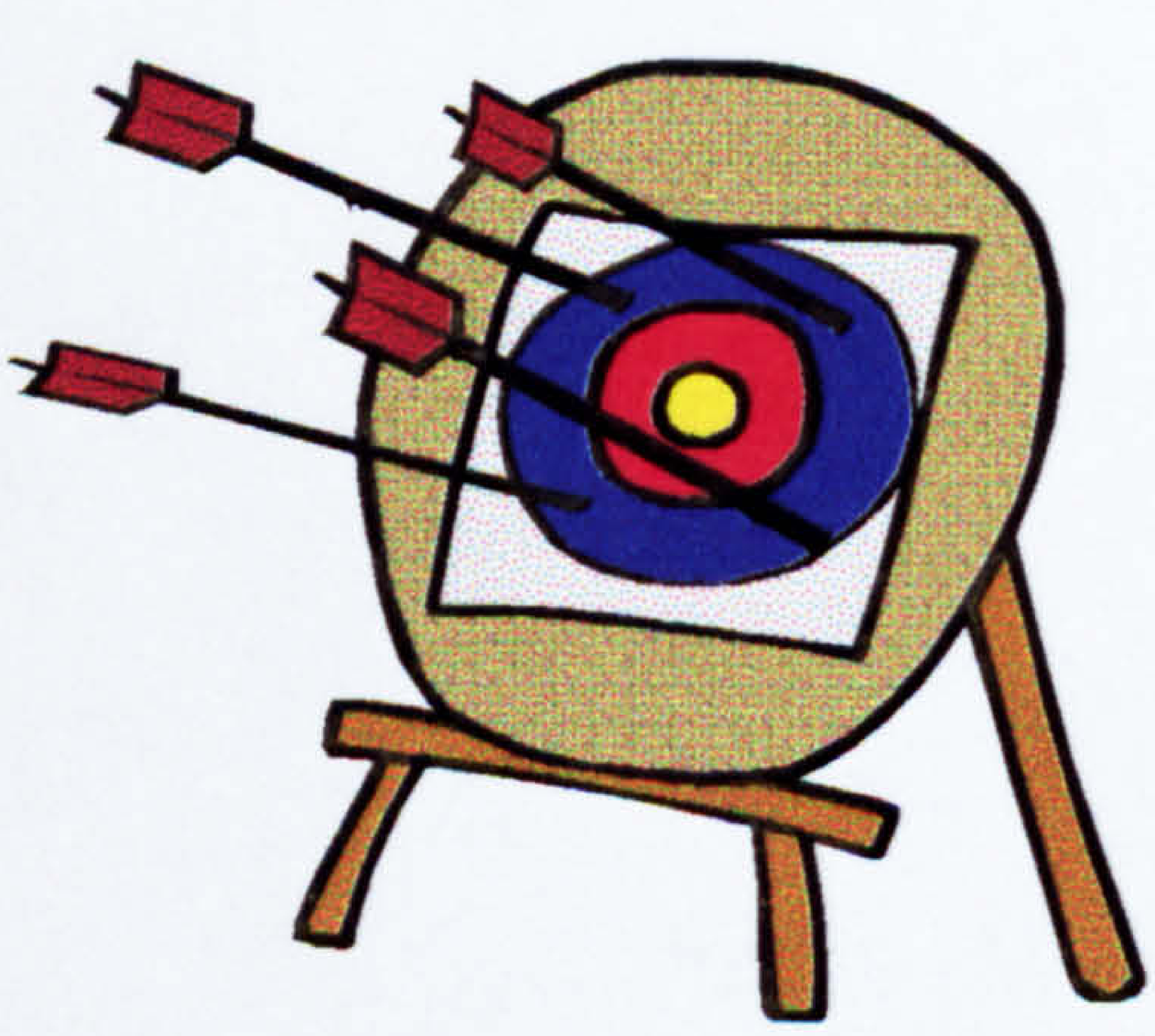
One archer hits the bulls eye every time in a tight cluster [accurate and precise]; one misses the bulls eye but is tightly clustered [precise but inaccurate]; one misses the bulls eye with a wide spread but the average of his 4 shots is in the bulls eye [imprecise but may give an accurate answer if all shots are averaged together]; and the other misses the target altogether. The ideal is the first archer but the second can be useful if the amount of his bias is constant and adjustable. The third may be useful because on average the result is in the bulls eye but since we usually only make one measurement little faith can be placed in the result so it is random error. The four target demonstrates no correct answers and the archer requires further training.



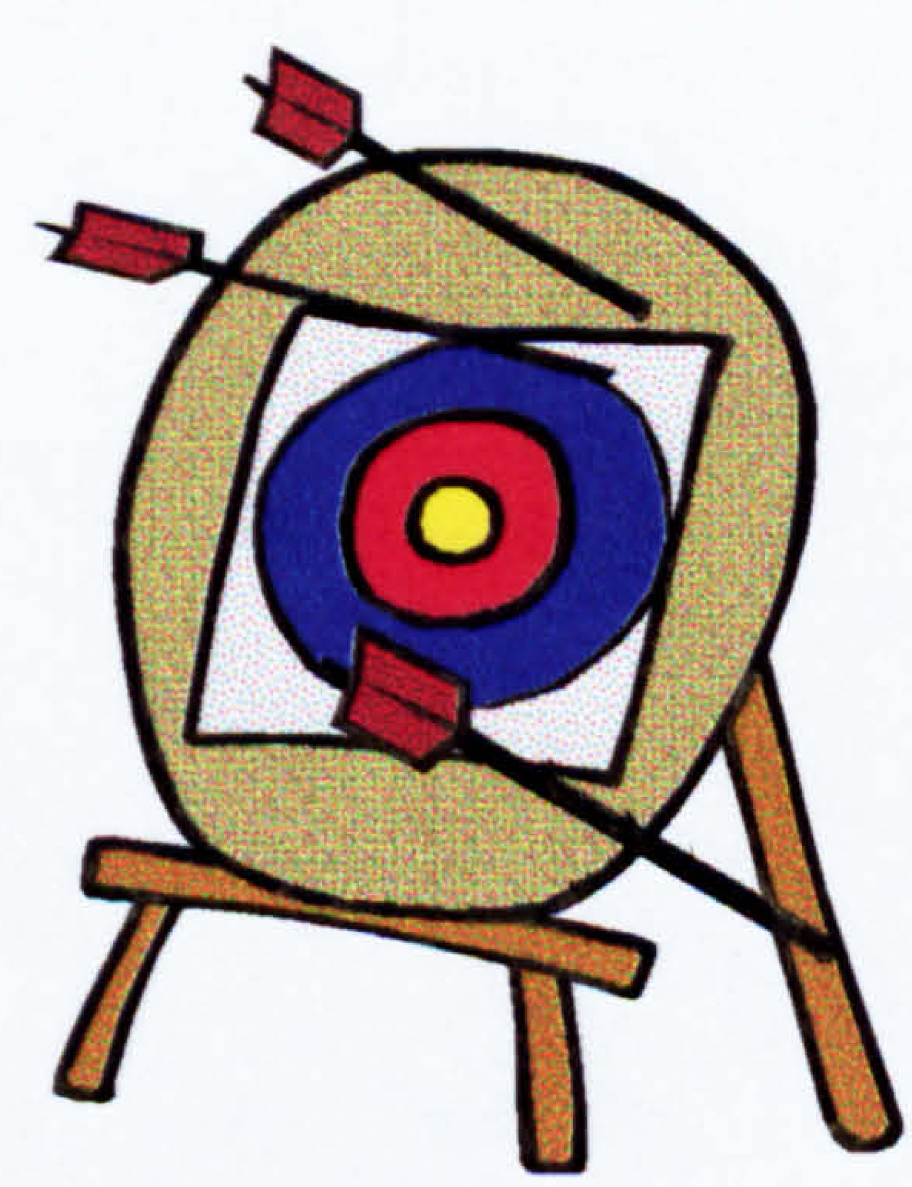
PRECISE AND ACCURATE



PRECISE BUT INACCURATE



IMPRECISE AND INACCURATE BUT MAY GIVE CORRECT ANSWER



IMPRECISE AND INACCURATE

8.2.2 Nurse Survey

A letter, questionnaire, and twelve photographs of Caucasian patients pressure ulcers, selected from the 30 photographs examined by the consensus panel, was sent to Tissue Viability Nurses, District Nurses, Acute Hospital Nurses and European Pressure Ulcer Advisory Panel members (see Appendix 1). The subjects (N=200) were recruited from the Tissue Viability Society, five Community Trusts and five Acute Trusts in the England and Wales over a three-month period.

The questionnaire asked for brief details of the nurses' qualifications, the number of years since qualification and the origins of their current knowledge of classification of pressure ulcers e.g. books, study days or courses (see Appendix 1). To identify whether training affected competency, the classification system currently in use was recorded together with information on quantity and quality of any training they had received on this system. The questions were based on a previous questionnaire validated by Russell (1996). Descriptions of the Stirling plus digits and EPUAP classifications were provided and nurses were asked to grade the images, using both systems

8. 2 3 Hypotheses and Aims

Using Computer Image analysis what is the level of agreement with Classification systems in the treatment of pressure ulcers?

To use Stirling and European Pressure Ulcer Advisory Panel classification systems , to test reliability of nurses and expert opinion against computer assessment of pressure ulcers?

The aims of the study are:

- To examine the nurse knowledge on the classification of pressure ulcer.
- To examine the ability of the nurses using the Stirling and the European Pressure Ulcer Advisory Panel system to produce reliable results.
- To determine the accuracy and precision of the information provided by nurses using these grading systems.
- To discover the accuracy and precision of nurses classification of sores compared to the sector of work the nurses are in.

8.2.4 The Pilot

The pilot was a study of four nurses to test the methodology. These subjects were two Tissue Viability Nurses one being member of the European Pressure Ulcer Advisory panel, one Acute Nurses and one District Nurses. The second part of the study was a questionnaire and the nurses were asked the qualification, grade, number of years qualified and how the knowledge has been obtained on classification of pressure sores. The final part was to identify twelve digital photographs of pressure sores against the Stirling plus digits and the European Pressure Ulcer Advisory Panel (EPUAP).

The data was analysed using access data base to discover if there are any refinements and modifications that are required both to the questionnaire and the photographs that are to be used for the classification of sores (see appendix 4). Modification to the access database was required and the questionnaire elicited the answers that required to be investigated. The photographs did not require any adjustment as the participants were able to grade all the photographs.

Results from the pilot demonstrated that a variety of grade of nurses was survey and all had over ten years experience. Two of the sample had received post basic education on classification of pressure ulcer interestingly theses were not the two Tissue Viability Specialist. Two nurses considered their knowledge to be fair and the other nurses good a district nurse and Tissue Viability Nurse Specialist. The origins of their education were considered to be from journals, academic courses and study days. Reading habits on classification on pressure ulcers demonstrated one Tissue viability Nurse Specialist had read in the last 1-3 months, and two participants had read last 4-12 months (one of these being a Tissue Viability Nurse Specialist), one district nurse was over 12 months.

Journals

Journal	Category of Nurse	Number of participants
Professional Nurse	TVN	1
JournalAdvanced Nursing	Acute	1
Journal of Wound Care	TVN	2
Tissue Viability Journal	TVN	2
Nursing Standard	Acute/TVN	2
British Journal of Nursing	TVN	2

All participants gained their knowledge from journals and three of participants were not happy with their current level of knowledge; Two of which were Tissue Viability Specialist and one Acute nurse but the District Nurse was happy with their knowledge. Topics for further education were physiology of pressure ulcers, non blanching and product information. Current classification systems the two Tissue Viability Nurse Specialist used Stirling and the Acute and District nurse used Torrance. Two of the participants wished for a National grading system one Tissue Viability Nurse specialist and the District nurse. The results of the Classification systems demonstrated that the Tissue Viability Nurse Specialist were experience in both grading system and more consistent results were obtained using the European Pressure Ulcer Advisory Panel.

8.2.5 Inclusion criteria into the study

- A qualified nurse, with no less than three years post qualification.
- No nurses employed on an agency or bank staff will be included into the study.

8.2.6 Exclusion criteria

- If they have already taken part in the pilot.
- Nurse unwilling to participate.
- Nurse which is closely associated with myself and the knowledge of how the study is comprised.

8.2.7 Ethical approval

Since images of patients were to be distributed, ethical approval was sought from South Staffordshire Local Research Ethics Committee (LREC), and granted as the study did not affect patient care and no image could result in identification of any individual.

8.2.8 Precision and Accuracy: Statistical Methods

To assess precision and accuracy, the grading decision of the consensus panel was considered to be 'correct'; henceforth the term '*correct*' is used interchangeably with '*agreed with consensus panel*'. Since each image had a different grade assigned to it by the consensus panel, the variability of results was assessed by taking the difference between the grade assigned by each nurse and the consensus panel. Accuracy was assessed by calculating the mean of all differences and precision by the mean of the absolute values of the differences. Thus, a sequence of 4 results (0.4, 0.4, -0.4 and -0.4) would have an 'accuracy index' of 0 indicating that on average the assessment of grade was 'correct' and a precision index of 0.4 indicating that although the results are 'correct' *on average*, each individual value is actually at considerable deviation from the true estimate. The mean and standard deviation for the accuracy index and precision index broken down by work area of nurse and routine grading system in use was then calculated. Additionally, the proportion of images where the 'correct' 2-digit Stirling or 1 digit EPUAP grade was assigned was calculated. [See Footnote 1]

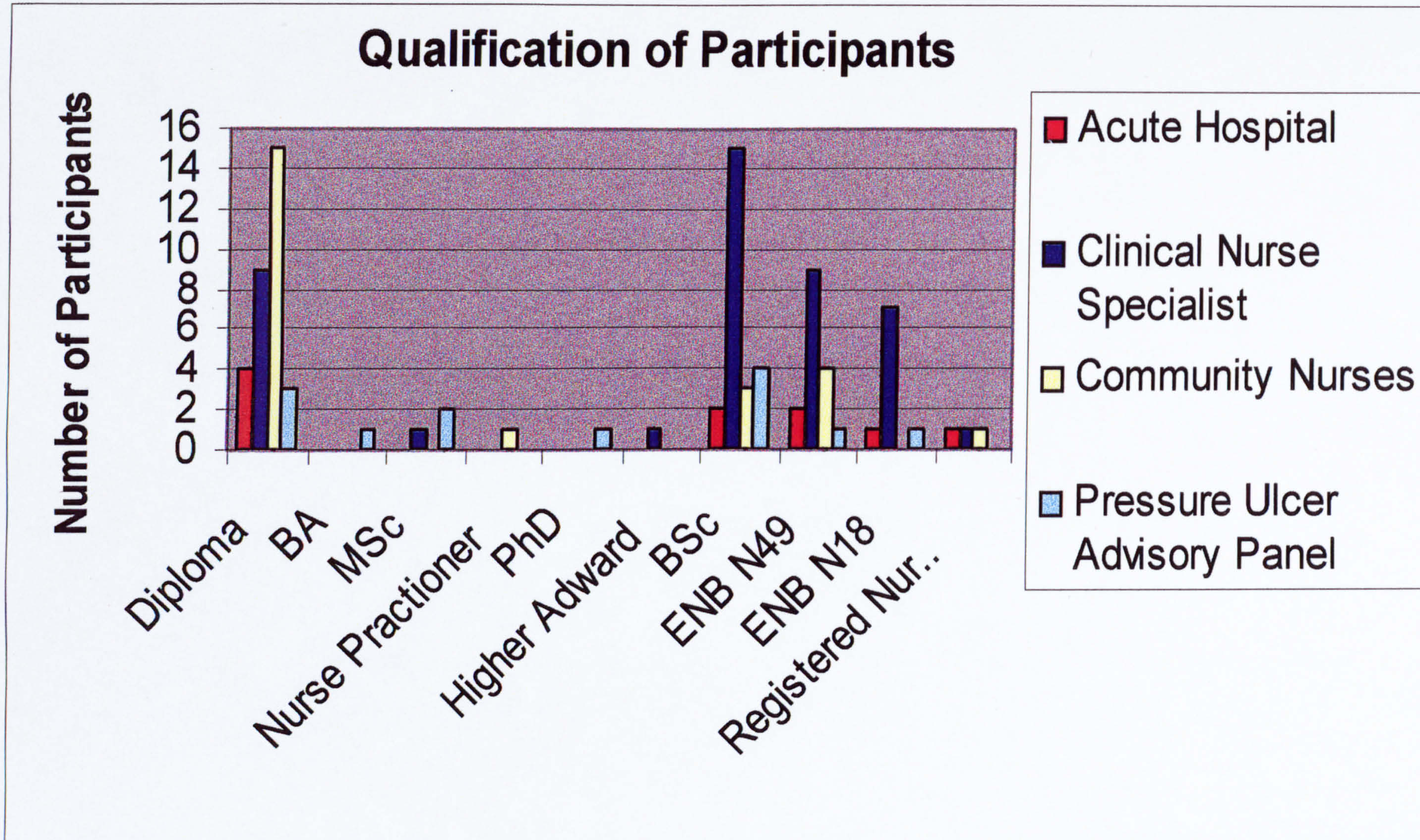
The sample population consisted of qualified nurses working in the Acute and community sectors with no less than three years post qualification, and members of the European Pressure Ulcer Advisory Panel. Nurses who had previously participated in the pilot study, or were closely associated with pressure ulcer research at Burton were excluded.

8.3 Results

The sample replies were almost evenly distributed: 27 Clinical Nurse Specialists, 21 Pressure Ulcer Advisory Panel members, 25 acute nurses and 24 community nurses (97 replies of 200) - just under a 50% response rate. Figure 8.2 shows educational qualifications by group.

The survey also enquired about other demographic features: clinical nurse specialists were grades G (22%), H (56%) and 22% I (22%); community nurses were grades D (4%), E (21%), G (50%), and H (21%);and as acute care nurses were grades D (12%), E (40%), F (28%) G (12%) and H 8%;most Pressure Ulcer Advisory Panel member's grades did not fit into the UK nursing grades scheme. Eighty-eight percent of clinical nurse specialists; 80% of Pressure Ulcer Advisory Panel members, 64% of acute care nurse and 64% of community nurses 64% had been qualified for over ten years. Community nurses had marginally more post basic training than the clinical nurse specialists.

Figure 8.2 Qualifications of nurses surveyed



Nine grading systems were currently in use amongst those surveyed. The Stirling classification system was predominately used by acute care nurses, whereas the EPUAP system was predominately used by the Pressure Ulcer Panel members. The majority of the sample (93%) wished to see a national grading system adopted.

8.3.1 Grading of Photographs

Figures 8.4 and 8.5 are bubble-plots showing the distribution of grades reported. The size of the bubble represents the number of responses at any given level.

8.3.2 Accuracy and Precision

Fig 8.6a & b show the accuracy and precision indices for all replies and for 3 subgroups. The numerical results shown in table 8.1. It is clear that on average, there is little difference between the consensus panel and the nurses surveyed. However, the precision index shows that on average there was an approximately 0.4 grade difference between the consensus panel and the surveyed nurses for the Stirling system and a 0.5 grade difference for the EPUAP system. However, one must consider this is 4x the minimum grade

Figure 8.3. Journals regularly read by nurses surveyed.

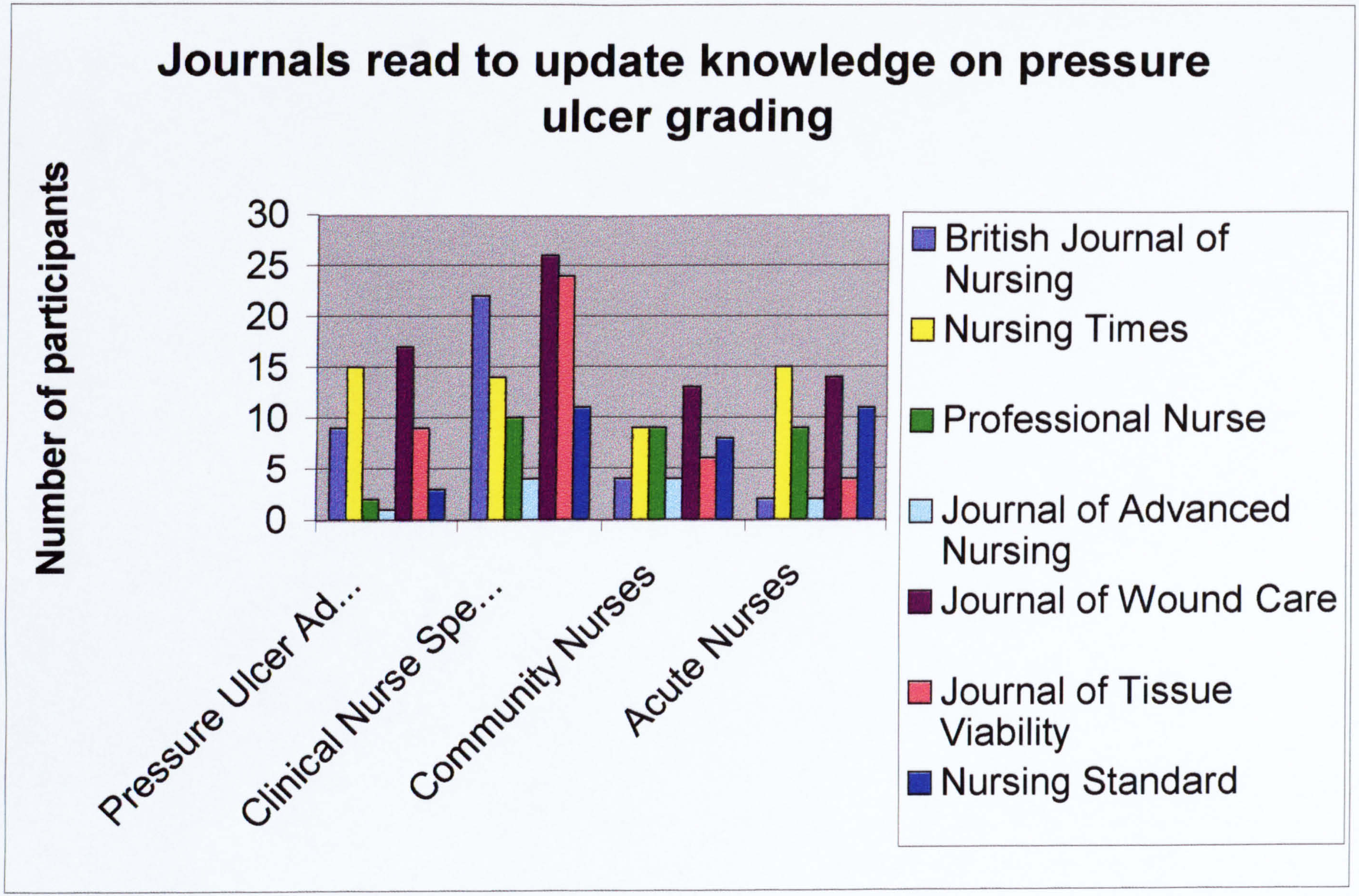


Figure 8.4. Bubble plot demonstrating range of Stirling grades reported. Horizontally shaded bubbles represent results in agreement with consensus panel. Bubble sizes give an impression of how many people gave similar grades.

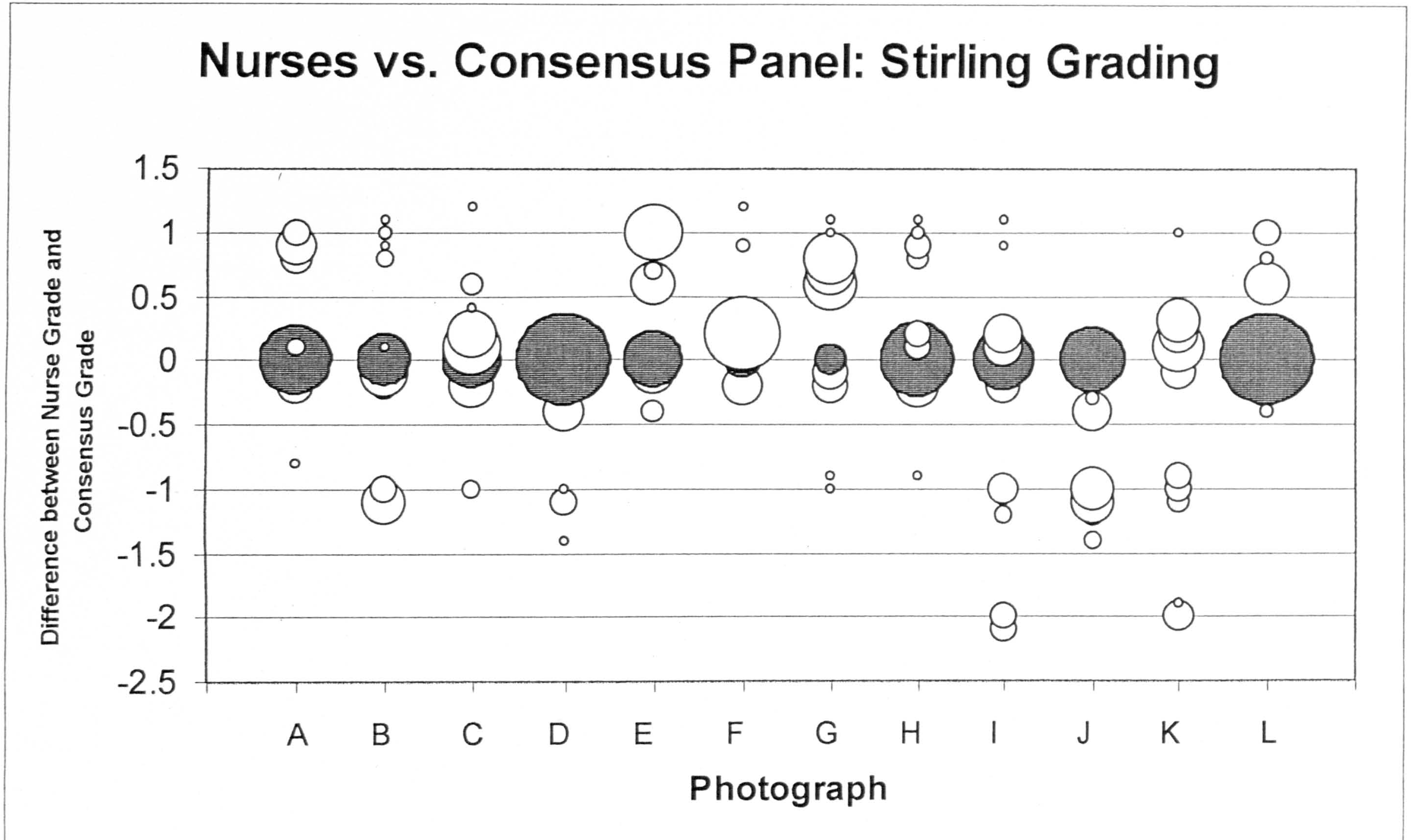


Figure 8.5 Bubble plot demonstrating range of EPUAP grades reported. Horizontally shaded bubbles represent results in agreement with consensus panel. Bubble sizes give an impression of how many people gave similar grades.

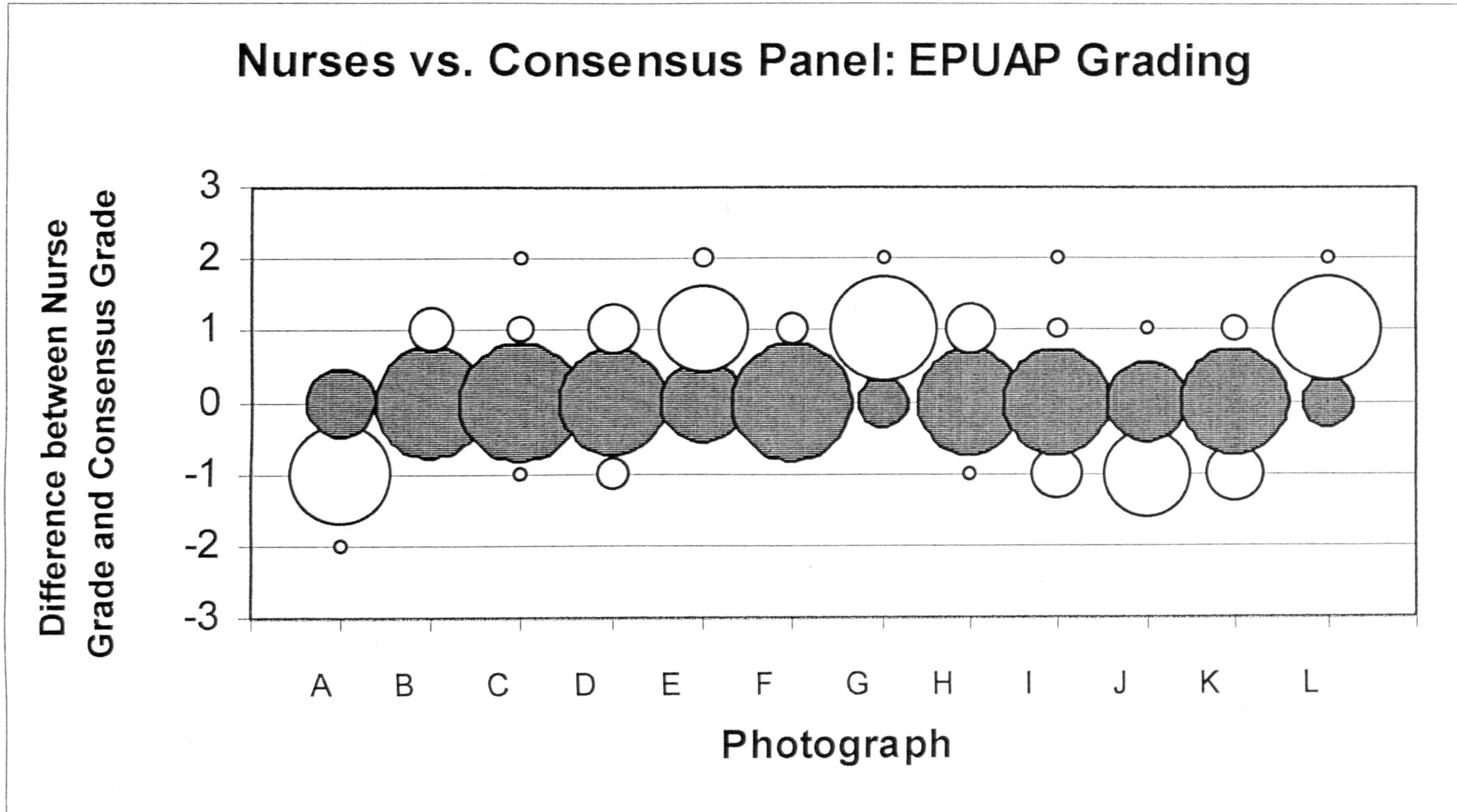


Figure 8.6a. Precision and accuracy of Stirling scoring comparing nurses who routinely used the Stirling score with nurses who use other scoring systems. Horizontal line represents mean response and vertical bars indicate ± 1 standard deviation. There are no statistically significant differences between the performance of any subgroup.
NOTE: only 1 pressure ulcer specialist nurse used the Stirling score so no standard deviation can be calculated.

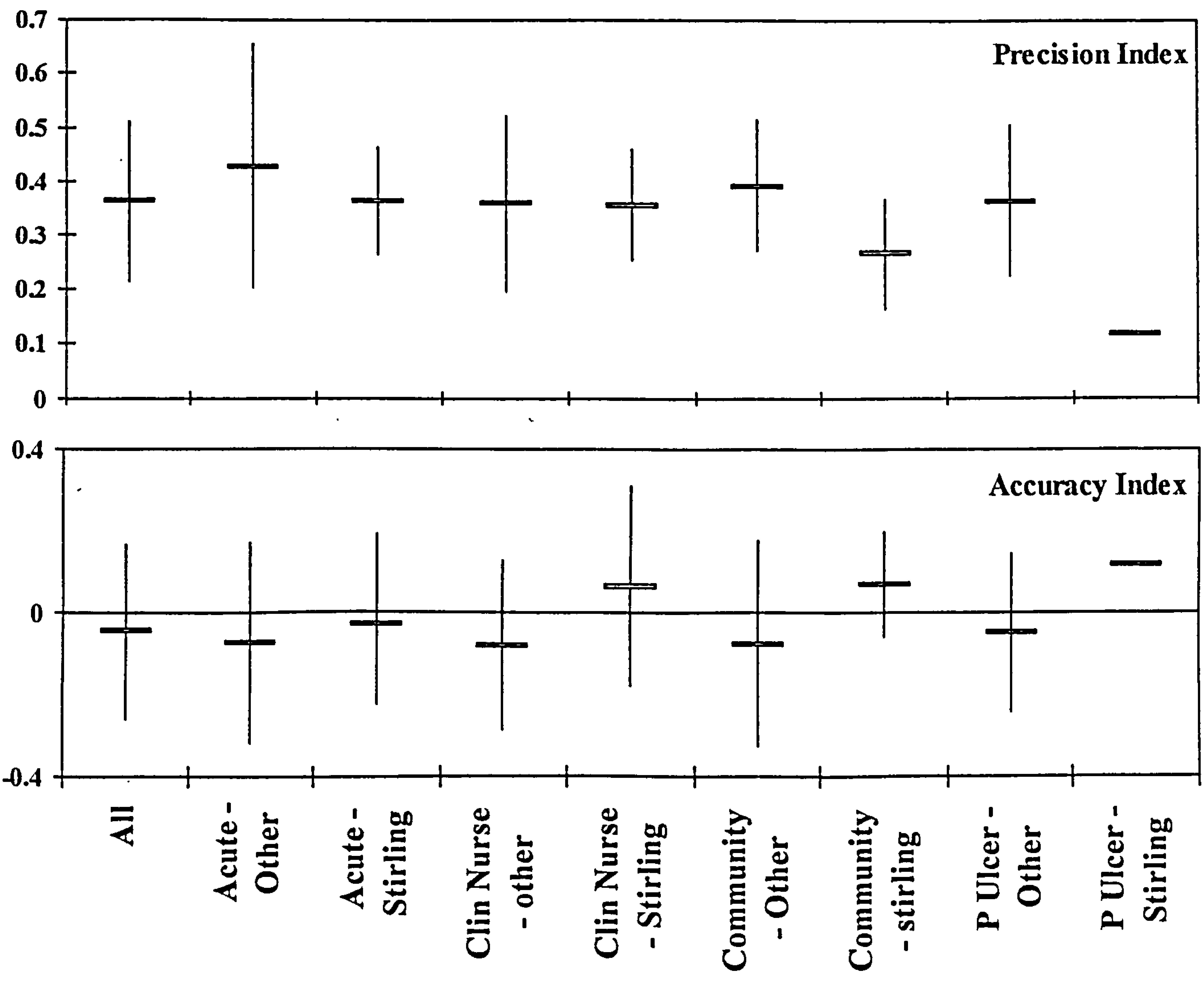
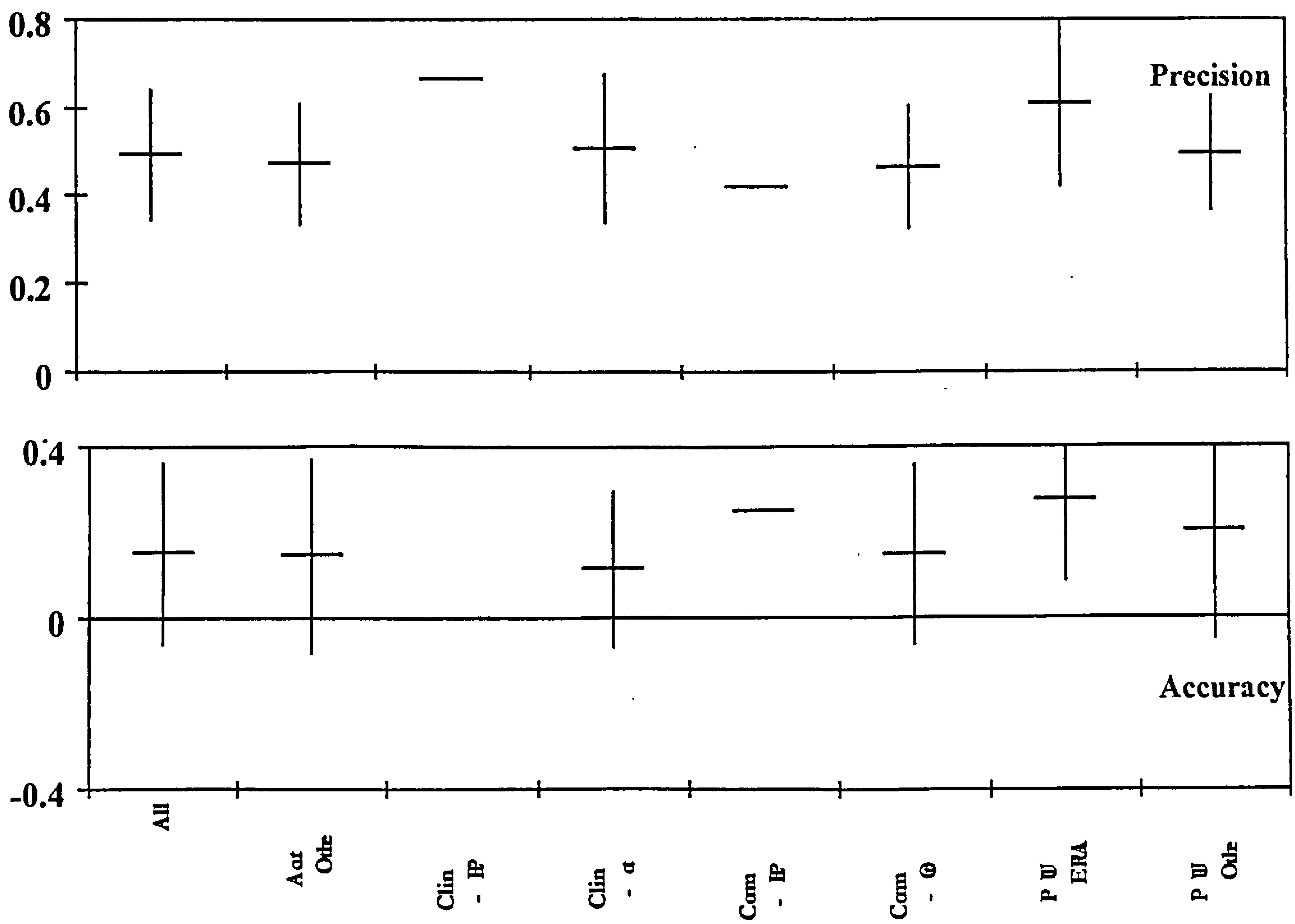


Figure 8.6b. Precision and accuracy of EPUAP scoring comparing nurses who routinely used the EPUAP score with nurses who use other scoring systems. Horizontal line represents mean response and vertical bars indicate ± 1 standard deviation. There are no statistically significant differences between the performance of any subgroup.
NOTE: only 1 pressure ulcer specialist nurse used the Stirling score so no standard deviation can be calculated.



<u>Table 8.1</u>

Precision and Accuracy Estimates.

Stirling Grading	Accuracy	Precision	N	Accuracy	Precision	N
All Nurses	-0.045 ± 0.21	0.36 ± 0.15	85			
	Stirling Users			Non-Stirling Users		
Acute Ward Nurses	-0.030 ± 0.22	0.36 ± 0.10	11	-0.073 ± 0.25	0.43 ± 0.22	10
Clinical Nurse Specialists	0.065 ± 0.24	0.36 ± 0.10	6	-0.082 ± 0.21	0.36 ± 0.16	21
Community Nurses	0.067 ± 0.13	0.27 ± 0.10	7	-0.076 ± 0.25	0.39 ± 0.12	13
Pressure Ulcer Advisory Panel Members	-0.1	0.12	1	-0.051 ± 0.19	0.36 ± 0.14	16
EPUAP Grading	Accuracy	Precision	N	Accuracy	Precision	N
All Nurses	0.15 ± 0.21	0.49 ± 0.15	86			
	EPUAP Users			Non-EPUAP Users		
Acute Ward Nurses				0.15 ± 0.22	0.47 ± 0.14	20
Clinical Nurse Specialists	0	0.67	1	0.12 ± 0.18	0.51 ± 0.17	26
Community Nurses	0.25	0.42	1	0.15 ± 0.21	0.46 ± 0.14	19
Pressure Ulcer Advisory Panel Members	0.28 ± 0.19	0.61 ± 0.19	3	0.20 ± 0.25	0.49 ± 0.13	16

increment for Stirling and 0.5x the minimum grade increment for EPUAP. Furthermore, there were relatively few nurses currently using the EPUAP grade routinely so with experience it would be expected that some improvement in grading accuracy would be achieved. In this light, the differences are more significant for Stirling grading than for EPUAP grading.

There is no statistically significant difference between any of the subgroups. It therefore appears that both Stirling and EPUAP indices appear to be consistent but have a wide spread - like the archer in target 3 of figure 8.1. Taking minimum increments into account, the EPUAP is relatively more consistent. This is reflected by the ability of nurses to get the same result as the consensus panel. In 30.2% of cases, the surveyed nurses gave the same 2-digit Stirling grade as the consensus panel, but using the EPUAP grading scheme 61.9% of grades agreed.

8.4 Discussion

8.4.1 Weaknesses of the study:

In the few previous studies of pressure ulcer grading, it has been recognised that photographs are not the ideal way to determine performance and that real life observations would be preferable, but since it is more practical to distribute images by post than patients, we used an image-based survey. This has the disadvantage that only one mode of examination (sight) is available to practitioners, and may mean that some of the discrepancies found are artefactual. The inability to calculate comparability statistics could be considered a weakness but is unfortunately unavoidable. However, we believe that the large discrepancy in accuracy Stirling and EPUAP (30.2% and 61.9% respectively) is adequate proof of superiority of the latter.

8.4.2 Strengths of the study

The original 'diagnosis' of pressure ulcer grade was not the opinion of a single tissue viability nurse but was a consensus opinion of 5 specialists. A good response to the survey was received (97 replies from 200). The study also examined other aspects of pressure ulcer knowledge such as sources of information and willingness to pursue further study.

In our study, we asked for grades to be reported using the Stirling system plus all 3 digits. Only a very few nurses did this and most only gave Stirling grades with the main grade plus 1 digit. This applied equally to nurses who routinely used Stirling and those who did not, and suggests that, in practice, the Stirling system is too complex. Our accuracy and precision analysis of the Stirling grades demonstrated that in general nurses did not identify the 'correct' result. Our findings corroborate Healey (1996) who demonstrated that the Stirling has poor reliability, particularly when used with second digits. The EUPAP grade correlated better with the consensus panel, although there are still some reliability problems.

Our results show that in general, Clinical Nurse Specialists in tissue viability are educated to high level (BSc or MSc) and are recognised by employers to be skilled as evidenced by their relatively high salary grades (22% on G grade, others higher). Other staff groups were also graded appropriately. Most of the nurses surveyed had been qualified ten years or more, but it should be borne in mind that this does not always mean that training has been undertaken recently. It is known that post-basic education on pressure ulcer prevention is seen frequently as low priority (Gould 1992, Russell 1996). Most clinical nurses specialists considered themselves to knowledgeable but believed further education would be valuable. Overall, the less-specialised nurses did not believe extra education on pressure ulcer grading would be of value. This is significant, because the majority of gradings are carried out by ward staff and not by nurse specialists and we have demonstrated a significant lack of consensus in pressure ulcer grades given by this group. However, unsurprising given that pressure ulcers care makes up only a small part of the general nurse's duties and time has to be allocated to education in other areas also.

This also calls into question the function of grading itself: are grades identified simply to enable comparative statistics to be generated, as they appear to have little clinical relevance. There is no research evidence to suggest that grading pressure ulcers has any importance on patients' outcomes or anything else. In 1986, it was claimed that nurses failed to put research evidence into practice because of a lack of educational opportunities (Gould 1986). Since then, study opportunities in terms of course availability have increased in numbers but availability of study time has not and may even have been reduced as workload has increased whilst staffing levels have decreased. To improve grading consensus or to introduce a National grading scheme, education sessions will be necessary - but it is first necessary to convince nurses that that specific education on pressure ulcer grading is important, as compared with education about other clinical problems. Controversially, It has been claimed that if nurses *'refuse to think for themselves, their roles may be assumed by health care assistants'* (Flanagan 2000). However, whether it is appropriate for nurses to collect statistical data of minimal clinical relevance is another matter.

Another major problem arising from the lack of consensus on grades is that prevalence and incidence data collected for Health Authority and Primary Care groups will not be dependable. The Government believes league tables are helpful because by 'naming and shaming' poor performers, they can be encouraged to improve (Sunday Times 2001). When performance data is as variable as our survey suggests, it becomes difficult to trust the raw data, and hence any league table derived from it. This problem has already been noted for pressure ulcer comparisons (Fletcher 1997).

We therefore echo and amplify previous calls for a National grading standard (Healey 1996, Harker 2000), introduced with sufficient education to ensure that agreement is maximised. However we also advise caution. Pressure ulcer grading using a numerical system has some drawbacks: a grade 4 sore is not necessarily twice as bad, or twice as big or twice as anything as a grade 2 sore. It is possible that large 'low grade' sores may be upgraded to indicate the degree of clinical significance, and vice-versa for small 'high grade' sores. Furthermore, the site of an ulcer may have clinical significance. It was attempted to synthesise all of these features into a grading system. However, as we have demonstrated this does not work and leads to imprecision.

Further research to investigate misreporting of current grades, non-numerical scales, the importance of superficial and full-thickness lesions and the significance of blanching / non-blanching erythema may all shed light on this complex area.

8.5 Conclusion

The purpose of a grading system is to enable communication between professionals using a common scale on which it is believed like always equals like. Neither of the classification systems used in this study was completely reliable and accurate but the EPUAP system was simpler and more accurately used than the Stirling system but gives little clinical information. The significant variation demonstrated here indicates that the Stirling score fails to achieve the commonality of interpretation that is essential for meaningful comparison to be made.

This study has many implications:

- Classification of pressure ulcers is not easy.
- A simple grading system such as EPUAP generates more consensus than a complex system. However, if one were to consider that this demonstrates that EPUAP is 'better' than the Stirling system, it still does not demonstrate that it is the 'best' grading system as there are many alternatives that have not been considered. Further research to develop an 'ideal' system would be required, if a national system is thought desirable.

❖ Clinical Nurse Specialists in tissue viability are highly educated but believe they should continue to learn pressure ulcer grading.

❖ Any grading system must be cascaded down to the nurses at ward level to enable audit.

❖ The reluctance expressed towards more education on pressure ulcer grading at ward level may in future hinder change and introduction of yet another different grading system in the future.

Although a perfect grading system may be impossible to achieve, we need to continue to work towards understanding what a grading system should provide and how this can be achieved.

Footnote 1

It may be thought appropriate to compare the performance of each grading scale using kappa testing. However, the kappa test applies when the two comparator scales have the same trait prevalence (distribution) and base-rate. Since the EPUAP grade scale is the set {1, 2, 3, 4, 5} and the Stirling scale is the set {1.1, 1.2, 1.3, 1.4, 2.0, 2.1 ...5.4} the two are compatible and it is not possible to calculate a kappa statistic. The accuracy and precision index are also affected by the same 'set' problem that prevents kappa calculation. Since the minimum increment for EPUAP is 1, the variance as a result of a 'mis-grade' is far more severe. Therefore, the most effective method of interpreting whether agreement is achieved is to examine the raw frequency of agreement.

is in the bulls eye but since we usually only make one measurement little faith can be placed in the result, so for practical purposes this archer is also useless.

Chapter 9

To investigate hue intensity and saturation in comparison with the classification of two pressure sore grading systems

Chapter 9
To investigate hue intensity and saturation in comparison with the classification of two pressure sore grading systems

9.1 Background

Classification of pressure ulcers is very complex. In particular the first stage of a pressure sore is very difficult to define. The four stages of hyperaemia make it confusing for the practitioner, whose comprehension of the aetiology of pressure sores becomes clouded (Collier 1999). There appears to be consensus on grade 3+ sores because the aetiology of these pressure sore are clearly defined. Accurate identification of all stages needs to be understood fully in order to enable pressure sores to be prevented or treated early enough.

Eighty per cent of pressure ulcers are superficial (Norton et al 1975) so could early detection can help prevent the development of a deep pressure ulcer. The government is placing great emphasis on pressure ulcer management: Essence of Care (2001) National Institute for Clinical Excellence Pressure ulcer risk assessment and prevention. "*Healthcare professionals should be aware of the following signs which may indicate incipient pressure ulcer development: persistent erythema; non blanching hyperaemia (NICE 2001)*".

Evidence is accumulating that hyperaemia and non hyperaemia persistent redness are identifiable risk factors in the development of a pressure ulcer and that the subsequent nursing care provided , will hopefully be successful at reversing skin damage (Nixon and Gough 2001).

On the problems with any classification of pressure ulcers is the sensitivity, specificity and the predictive validity of that tool that is employed for the screening assessment.

General Principles of Screening

Screening can be defined as the presumptive identification of unrecognised disease or defect by the application of tests, examinations or other procedures which can be applied rapidly. Thus, screening tests sort out those apparently well people who may have a condition from those who probably do not i.e. screening tests are not diagnostic and if the screening test gives a positive result, a diagnostic test is required (Whitby 1974, Galen and Peters 1986, Mant and Fowler 1990).

Screening individuals can be divided into four groups:

True positives (TP): those individuals who have a positive screening test result and who have the condition screened for.

True negatives (TN): those individuals who have a negative screening test result and who do not have the condition screened for.

False positives (FP): those individuals who have a positive screening test result but who do not have the condition screened for.

False negative (FN): those individuals who have a negative screening test result but do not have the condition screened for.

These groupings are useful because they allow the calculation of indices which can be used to assess the effectiveness of a screening tool or program.

The derived indices are:

Sensitivity : (equivalent to detection rate) sensitivity is defined as the ability of a test to give a positive result in people who have the condition being screened for (i.e. positivity of disease). The sensitivity is the proportion of patients that are correctly identified by the test (Altman et al 2000).

$$\text{Sensitivity} = \frac{TP}{TP+FN} \times 100\%$$

Specificity: (equivalent to - false positive rate): specificity is defined as the ability of the test to give a negative result in people who not have the condition being screened for (i.e. negativity in health). The specificity is the proportion of true negatives that correctly identified by the test (Altman et al 2000).

$$\text{Specificity} = \frac{TN}{TN+FP} \times 100\%$$

Predictive value: predictive value gives an idea of how effective a test is in the clinical environment. The predictive value of a positive result is the likelihood that a positive result means that the condition is present and similarly, the predictive value of a negative result gives the likelihood that a negative result indicates the condition is absent. The predictive value is probably the most important test characteristic because it varies according to the frequency of the screened condition. (Whitby 1974, Galen and Peters 1986, Mant and Fowler 1990). A positive predictive value is the proportion of patients with a positive test result who are correctly diagnosed. A negative predictive value is the proportion of patients with negative result who are correctly diagnosed (Altman et al 2000).

$$\text{Predictive value of a +ve result} = \frac{TP}{TP+FP} \times 100\%$$

$$\text{Predictive value of a – ve result} = \frac{TN}{TN+FN} \times 100\%$$

Efficiency: efficiency relates to the overall performance of screening test.

$$\text{Efficiency} = \frac{TP + TN}{TP + FP + TN + FN} \times 100\%$$

A sensitive test is one which rarely misses disease and a specific test is one which rarely causes false alarms. In general practice the most important feature of screening test is its specificity because the incidence of any particular disease is generally low. In a hospital setting sensitivity is more important because the population under scrutiny is already selected as being "ill" and the prevalence of disease is thus greater (Mathers and Hodgkinson 1989) i.e. the predicative value of the parameters is affected significantly by the prevalence of the condition being screened for.

Very few studies exist on the use of Hue Saturation Intensity for measurement and classification of pressure ulcers (Russell 1999). New methods of defining an early stage of pressure ulcers need to be discovered and could have great economic benefit to the Health Service, and ultimately in patient care which results in decreased in the pain and discomfort from pressure ulcers.

9 2 Methods

9.2.1 Hypotheses and aims

Can pressure ulcers be assessed by using Computer Image analysis and can the results of the analysis be used to make prognostic assessment's and indicate early treatment?

To test if pressure ulcers can be classified using image analysis, Hue saturation and intensity in order to make prognostic assessment of early skin damage?

Aims

- To determine whether different grade of pressure ulcers exhibit specific hues.

- To develop a consensus of opinion from four experts on the grade of pressure ulcers which can be compared with Hue.
- To determine if the 12 images from the questionnaire give hues that enable identification of the grade of pressure ulcers.

Data were analyzed from the randomised control clinical trial of Pegasus Cairwave & proactive seating cushion and the Nimbus 3 & Aura seating cushion for the treatment of pressure sores. The trial collected data on 141 patients over a 19 month period. All grade 2 sacral pressure sores and above on the Torrance classification were photographed digitally. They were then analysed using a special macro (see chapter 6).

9.2 2 Pilot

A pilot study consisted of 19 skin tones 19 grade 2a and 14 Grade 2b (using modified Torrance system (see table 9.1)). The raw data were examined to determine whether there are any common factors relating HSI and a particular type of classification of pressure sores. Next, using the data from the primary study (see chapter 6), a random selection of patients were chosen. Initially, a Microsoft Excel package was used to calculate means and standard deviation of the skin tone, grade 2a and 2b pressure ulcers and these were plotted (see table 9.2). Data were then transferred into SPSS for Windows and a box & whisker plot drawn (see figure 9.1).

This is only a small sample of patients that have been analysed (N= 33) and the preliminary findings appeared to suggest that early detection of pressure ulcers was possible.

9.2.3 Consensus Panel

A consensus panel of four experts' opinion on the Hue saturation and intensity box plots and the images used to derive them were discussed in comparison to the European Pressure Ulcer Advisory Panel classification. The panel visual assessed the box plots and photographs and agreed that HSI lined up well with the classification system . The panel were then asked to classify 33 digital images and compare them against the Stirling Plus digits and European Pressure Ulcer Advisory Panel. Twelve photographs were then randomly selected for the nurse reliability postal questionnaire on the classification of pressure sores using Stirling plus digits and European Pressure Ulcer Advisory Panel (see chapter 8 Russell & Reynolds 2001).

9.2.3 Precision and accuracy of the camera and lighting

In order to check the precision and accuracy of the camera and lighting, 10 arm and leg digital images were taken from four volunteers. The digital images were taken behind curtains on the same ward that was used for the trial, in a middle bed space next to the window at the same time of day, when the photographers took photographs of the trial patients. These images

Table 9.1

Skin assessment grades

0 No skin discolouration

1 Redness to skin blanching occurs

2a Redness to skin non blanching

2b Superficial damage to the epidermis

3 Ulceration progressed through dermis

Adapted from Nixon et al 1999

Figure 9.1

Box plots of hue saturation and intensity of the skin tones, grade 2a and grade 2b pressure ulcers

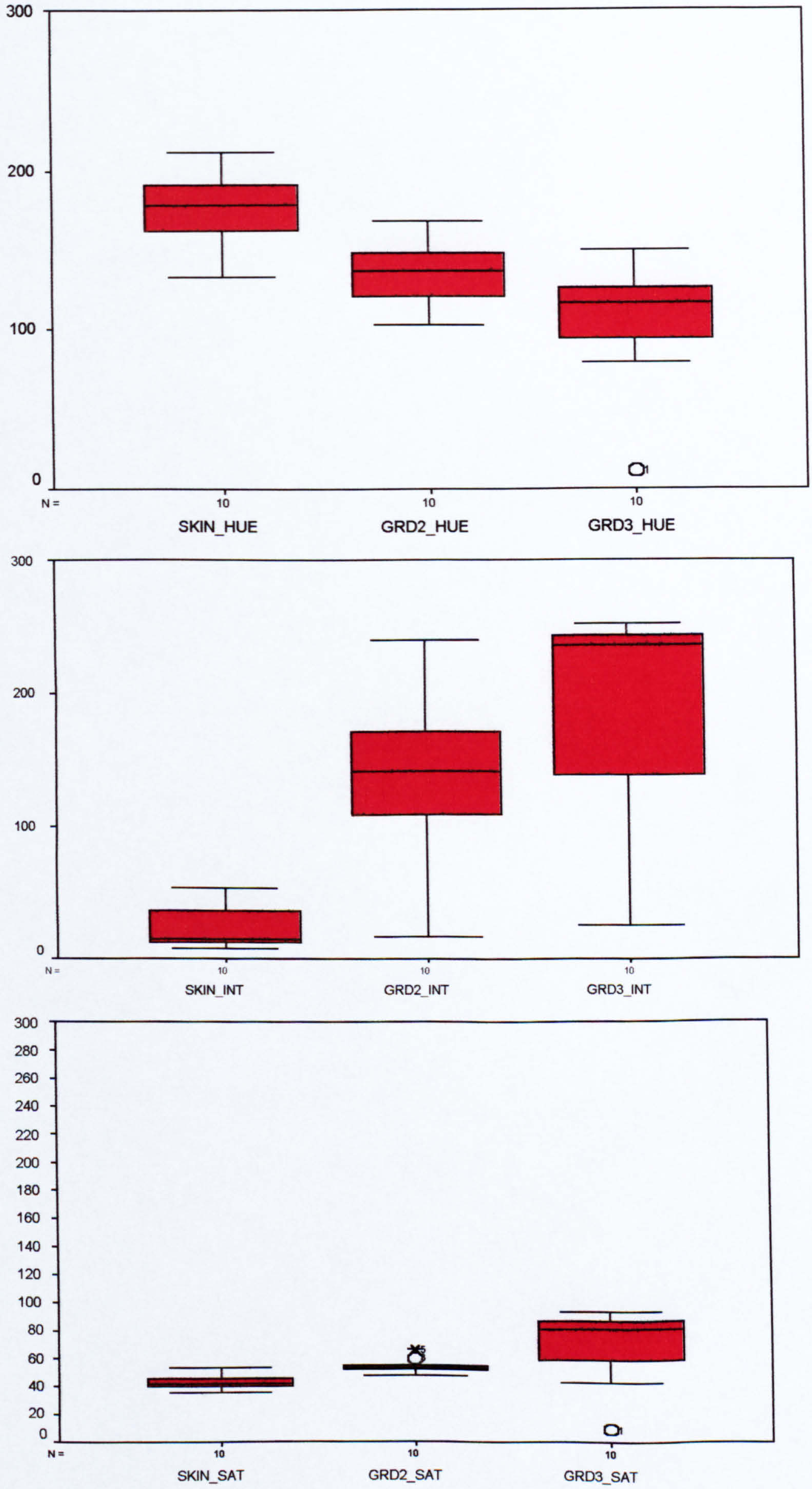


Table 9.2 Mean and Standard Deviation

		Hue	Saturation	Intensity
Skin Tone				
	median	190.04	41.90	14.69
	mean	179.12	41.99	21.10
	±sd	19.92	7.20	19.61
Grade 2				
	median	127.43	99.23	172.20
	mean	126.99	96.09	197.99
	±sd	19.04	6.09	64.99
Grade2b				
	median	119.61	93.93	232.91
	mean	111.32	79.36	212.49
	±sd	17.69	20.09	43.99

were then analysed using the special Macro, described early in chapter 6 using the rectangle box normally used for skin tone as the wound outline sequences. The data was then processed in the same method as the main study and transferred to Microsoft Excel package.

The sample population was 226 normal health volunteers, taken from the above study, 495 normal patients skin over the age 75, 510 grade 2a ulcers, 492 grade 2b ulcers and 53 grade 3 ulcers images. All images were analysed using image analysis data reported as an 8-bit number meaning that it has a range of 00000000 to 1111 1111 in binary which is equivalent to 0-255. At this point it was realised that traditional mean and sd statistics as used in the box and whisker plots (figure 9.1) did not function correctly. Hue saturation and intensity form constrained ranges with a wrap around of values being probable (see figure HSI cone figure 9.2). It is therefore possible for a result e.g. of the hue to range from a high value (e.g. 245) to a low value (e.g. 5) as a result of small negative changes in value (-15 units as well as the results of a large positive change (+ 240 units). This is a classic modulus arithmetic situation (see figure 9.3). Therefore, to calculate mean and ±sd for the data it was first necessary to examine the data to determine whether the mean value was on the 0-255 boundary or in the centre of the colour wheel. This was carried by plotting histograms to demonstrate the distribution of the continuous variables of hue saturation and intensity of normal skin of young healthy people, and patients with normal skin, grade 2a, 2b and grade 3 ulcers (see table 9.3) To demonstrate the construction of the data, radar plots were drawn showing the changes hue, saturation and intensity versus normal skin to grade 3 ulcers. If the distribution crossed the 255-0 boundary, the data was recentred to 128 by modulus addition, and the means and ±sd. re calculated and the resultant mean was again recentred by modulus subtraction of 128.

A further stage of analysis used the formula for an ellipse using Micro Soft Excel package to draw the Hue and Saturation on the normal skin, grade 2 a and grade 2b to demonstrate 1 and 2 standard deviation and demonstrate the variability of each group (see figure 9.12). The difference between 2a and 2b ulcers were tested by comparison standard errors of the mean (Statistics at Square One). No statistical significance was shown in Hue saturation or intensity. However to demonstrate the relative positions of grade 2a and 2b ranges, continued to be shown separately.

9.2.4 Formula for Ellipse

$$\frac{X^2}{a^2}+\frac{Y^2}{b^2}=1$$

$$\therefore$$

$$\frac{b^2X^2}{a^2}+Y^2=b^2$$

$$\therefore$$

$$Y=\sqrt{(b^2-\frac{b^2X^2}{a^2})}$$

Where X and Y = centre points and a and b = semi - major, semi-minor axes respectively. For the purposes of ellipse calculation, X was defined as the origin (0,0) and ellipses were then centred to their correct spot by addition of the relevant offsets.

e.g. from table 9.3; for Normal skin, semi-major axis for 1sd ellipse was 21.8 [≡ Hue sd], semi-minor axis was 15.0 [[≡ Intensity sd] and offset was (152.1,47.7) [≡ (Hue mean,Intensity mean)].

Finally the data from the questionnaire photographs using the consensus panel answers of European Pressure Ulcer advisory panel were plotted against the computer system Actual sores (see figure 9.13).

9.2 5 Ethical Approval

Ethical approval was given by South Staffordshire Local Research Ethics Committee (LREC) for the collection of data that was used in this study. Further approval was not required as data has already been collected from previous studies and would not involve further patient interventions.

9.3 Results

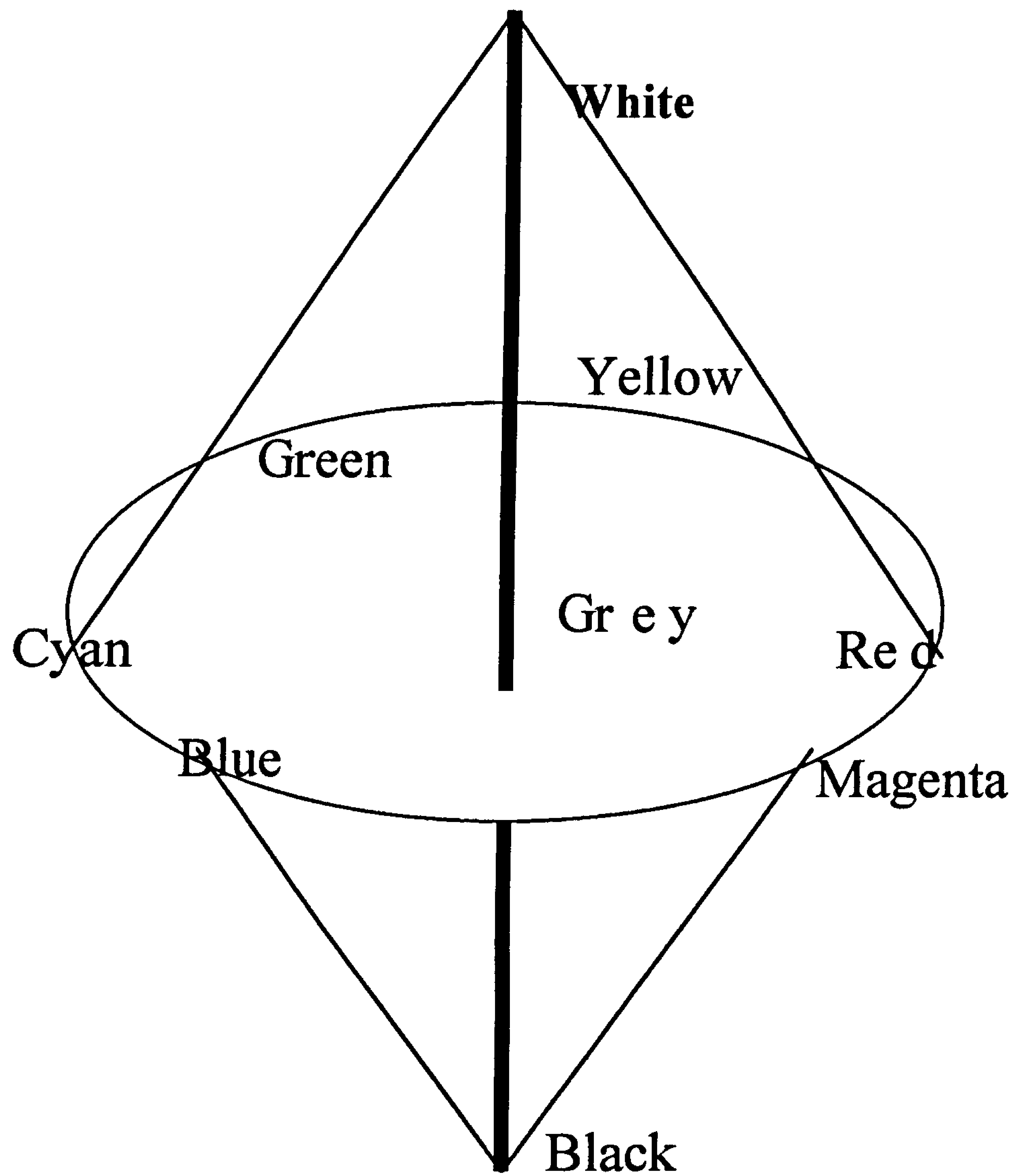
Table 9.1 shows that the Intensity of the skin, grade 2a and grade 2b sores graduates upwards, as does the saturation. The hue measurements graduated downwards from the skin tone to the grade 2b. Figure 9.2 gives the mean and standard deviation of hue saturation and intensity.

9.3.1 Bar Graphs

The normal skin of young healthy people (not patients) showed that the hue is distributed in the centre of the graph whilst the saturation and intensity

Figure 9.2

Bi -conic representation of Hue-Saturation and Intensity



Adapted from Russ (1999)

Figure 9.3

Classic Modulus Arithmetic

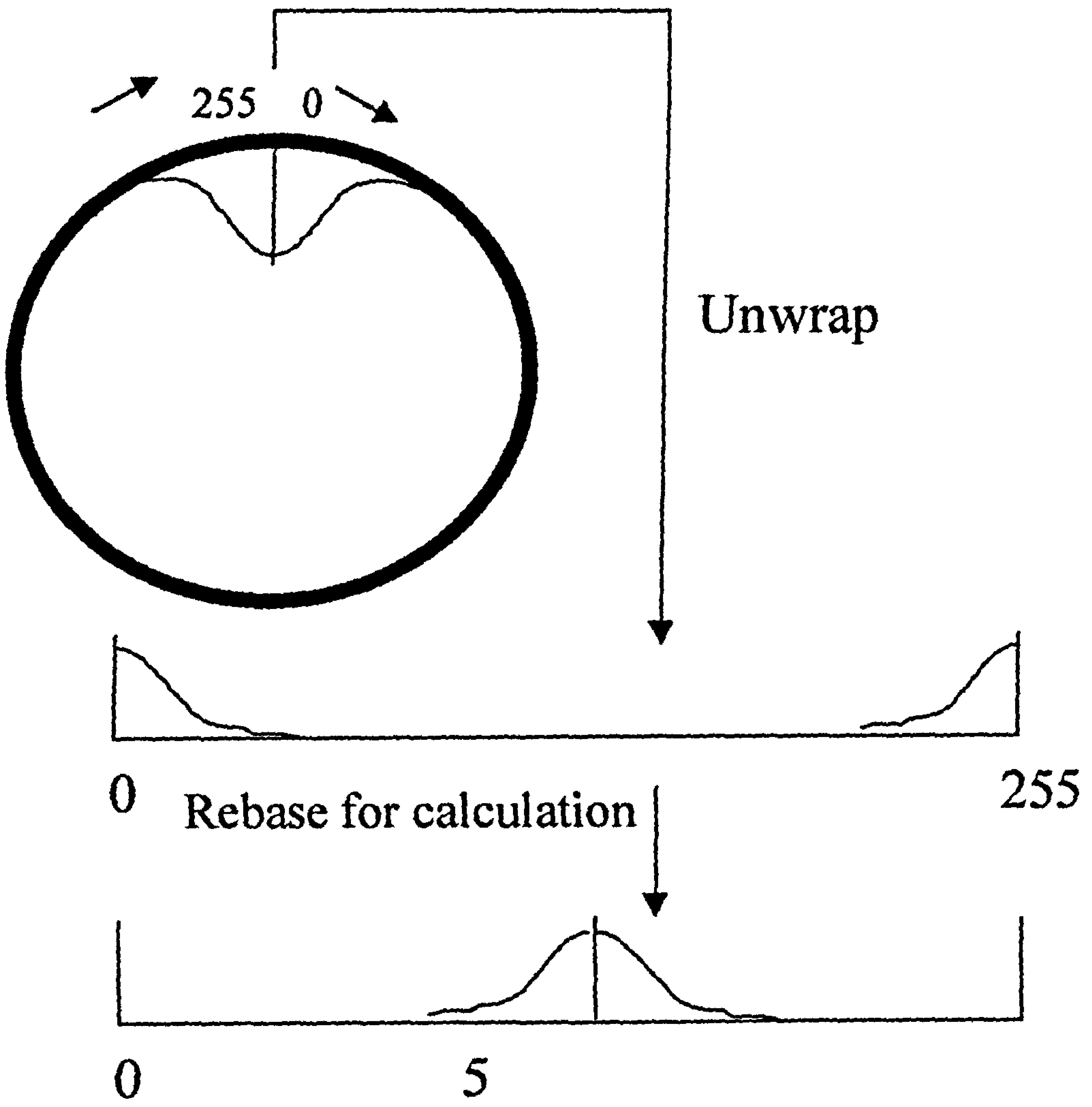


Table 9.3 Effect of Modular Calculation on Intensity values only

Normal Skin - Not Patients				Modular calculation for Intensity values only
	Hue	Saturation	Intensity	
max	201.3	83.9	226.5	
min	116.2	29.1	1.3	
mean	152.1	47.6	52.1	11.7
sd	21.8	14.9	60.6	50.0
N	266	266	266	266

Normal Skin - patients				Modular calculation
max	227.1	99.2	251.0	
min	92.0	15.7	5.2	
mean	180.6	44.7	24.6	15.3
sd	20.7	9.9	36.9	21.6
N	495	495	495	495

Grade 2a Patients				Modular calculation
max	204.2	126.0	248.3	
min	61.0	20.4	5.0	
mean	128.9	57.2	142.1	248.5
sd	19.7	10.0	65.9	75.8
N	510	510	510	510

Grade 2b patients				Modular calculation
max	216.9	155.7	254.9	
min	54.0	29.9	0	
mean	115.2	74.3	203.4	233.6
sd	25.6	19.3	62.3	39.8
N	492	492	492	492

Grade 3 patients				Modular calculation
max	181	124.3	250.2	
min	76.0	34.9	16.7	
mean	113.6	70.5	198.9	237.5
sd	18.3	16.0	60.2	46.1
N	53	53	53	53

are at the lower end of the graph see figure 9.4. With normal skin patient's the hue has moved to the end of the bar graph but the saturation and intensity remain at the lower of the graph see figure 9.5. Figure 9.6 demonstrated quite a different picture with 2a ulcers the hue had a nearly normal distribution curve. The saturation was still at the top end of the graph, but the intensity was spread evenly across the graph. The graph for the 2b ulcers, demonstrated another distribution of hues, in the middle with saturation next to the hues and the intensity at the extreme of the graph see figure 9.7. The graph for grade 3 ulcers demonstrated similarities between the 2b ulcer hues, and saturation were in similar places with higher frequencies and not so normal distribution curves. The intensity was in the same place with smaller frequencies. Figure 9.8 clearly shows a distribution which lies on the 0-255 boundary indicating the need for modulus correction.

9.3.2 Modular Statistics

Table 9.3 the mean and standard deviation (±sd) for hue saturation and intensity for each category. The mean ±sd was also calculated using modular statistics, this demonstrated a more definitive split between the normal skin of the healthy volunteers and patients skin. The modular mean for the 2a ulcers were at 248, ±sd 75, whereas the 2b ulcers 233. ±sd 39 and the grade 3 ulcers 237,±sd 46 very close to each other.

9.3.3.Radar Plots

The 0-255 boundary plots at 12:00 o'clock position . Data were calculated by selecting the data into bins and counting the frequency of each bin and then plotting in a radar format. Figure 9.9 demonstrates clearly that skin intensity changes from low to high values as a grade 3 ulcer develops. Intermediate data (not shown graphically but in table 9.3) prove that the changes occurred by the " short route" i.e. 50 → 0 → 237, as apposed to the "long route" 50 → 150 → 200 → 237. The hue, saturation and intensity were plotted against normal skin > grade 3 ulcer. There were also distinct differences in the hue of normal skin and grade 3 ulcer (see figure 9.10-9.12). In the saturation plot, the position has moved round about 90° and the intensity plot of normal skin plot has moved nearly up to the zero and grade lies the other side of the zero.

9.3.4 Ellipse

Figure 9.13 shows that the hue and saturation distributions for grade 2a and 2b ulcers over lapped significantly. Standard deviation statistical tests showed no significant difference, but for clarity both ellipses are shown in figure 9.13. This demonstrates that majority of the data plots in the expected ellipses e.g. 10 of the 12 normal skin tone results are in the normal ellipse; all of the pressure ulcers are within the red 2b ellipse, but the purple 2a ulcer ellipse also encloses 1 normal skin tone. The effectiveness of the HSI method was evaluated using χ^2 statistical tests for sensitivity and specificity.

Figure 9.4

Normal Skin - not patients

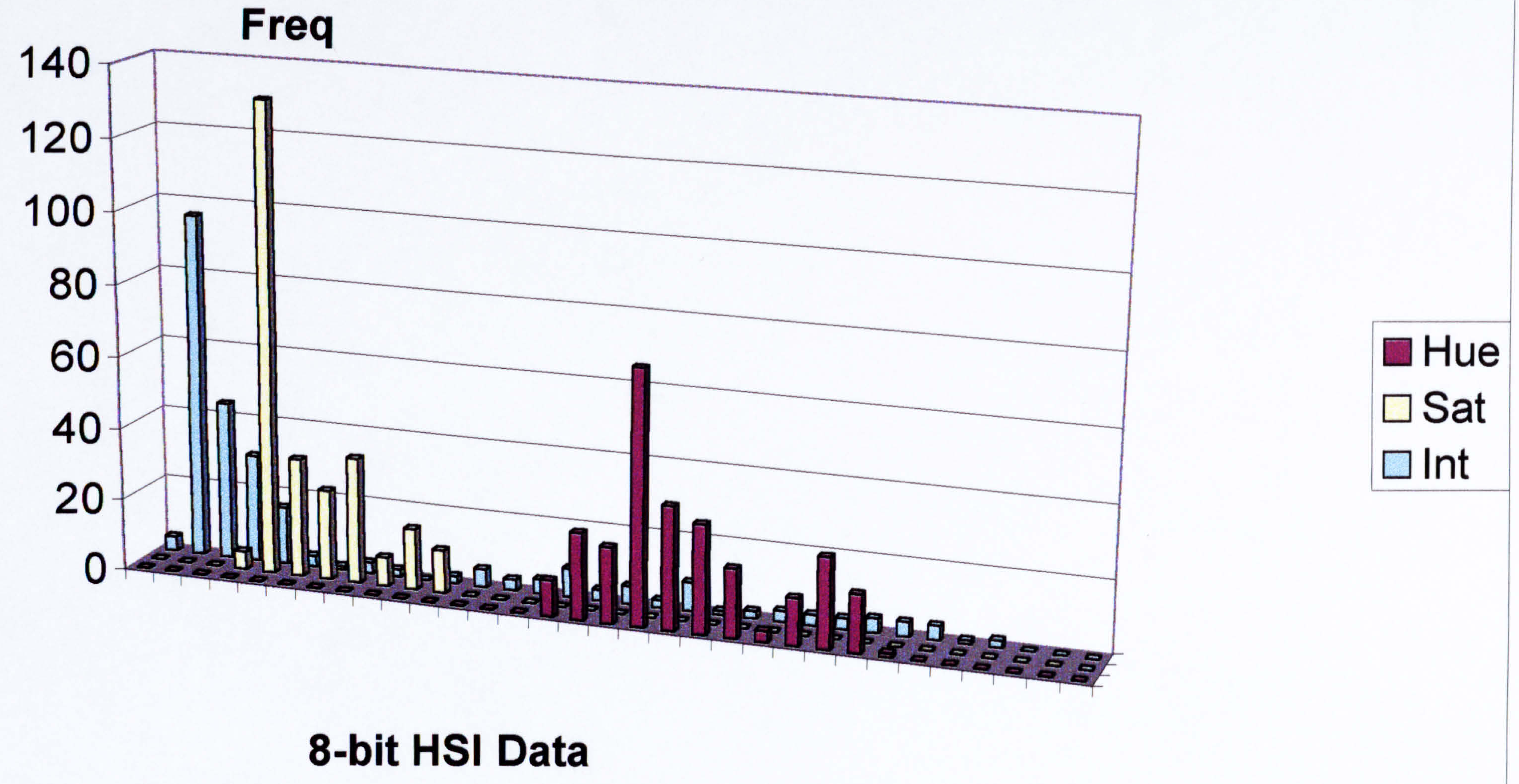
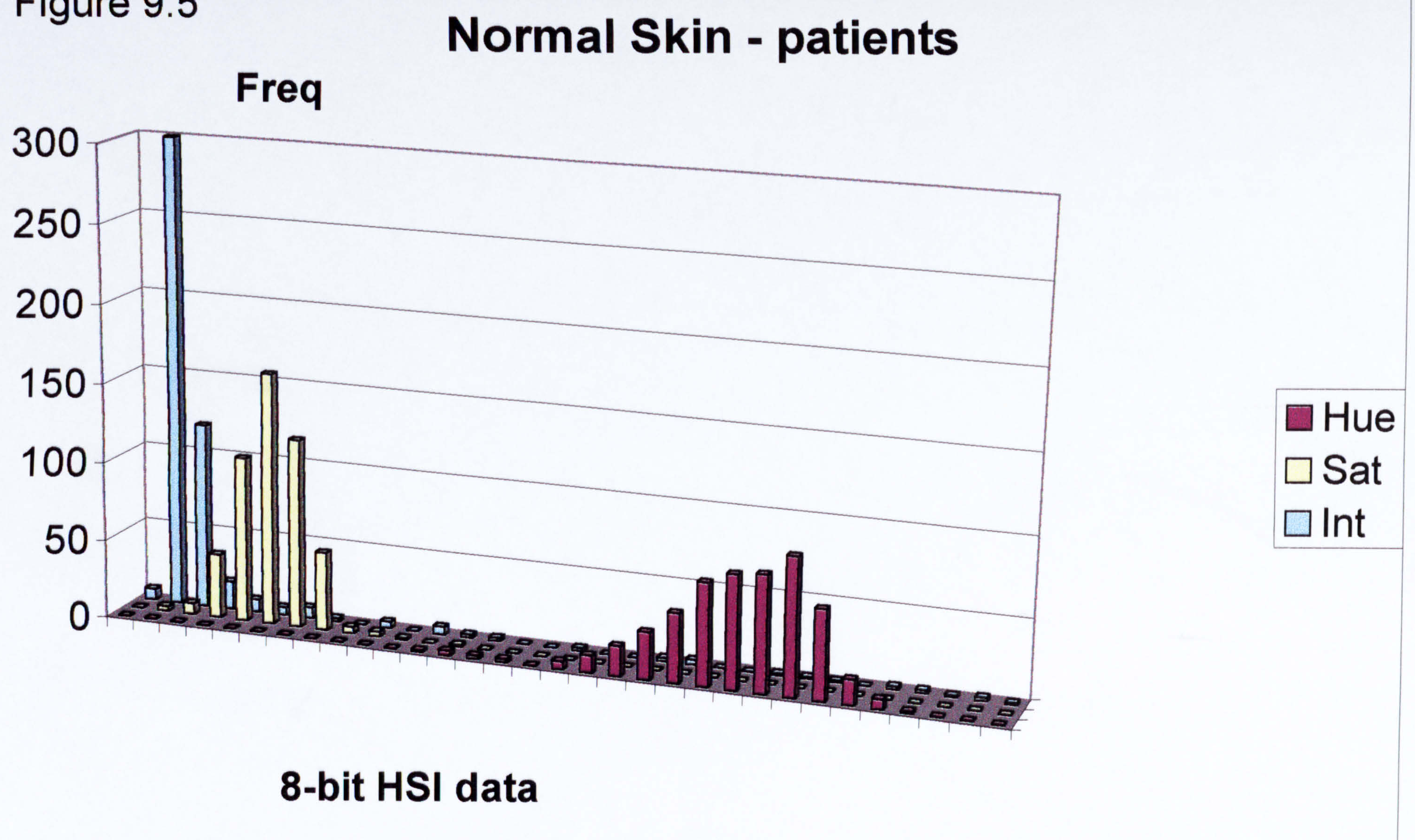


Figure 9.5


Normal Skin - patients
Freq
300
250
200
150
100
50
0
Hue
Sat
Int
8-bit HSI data

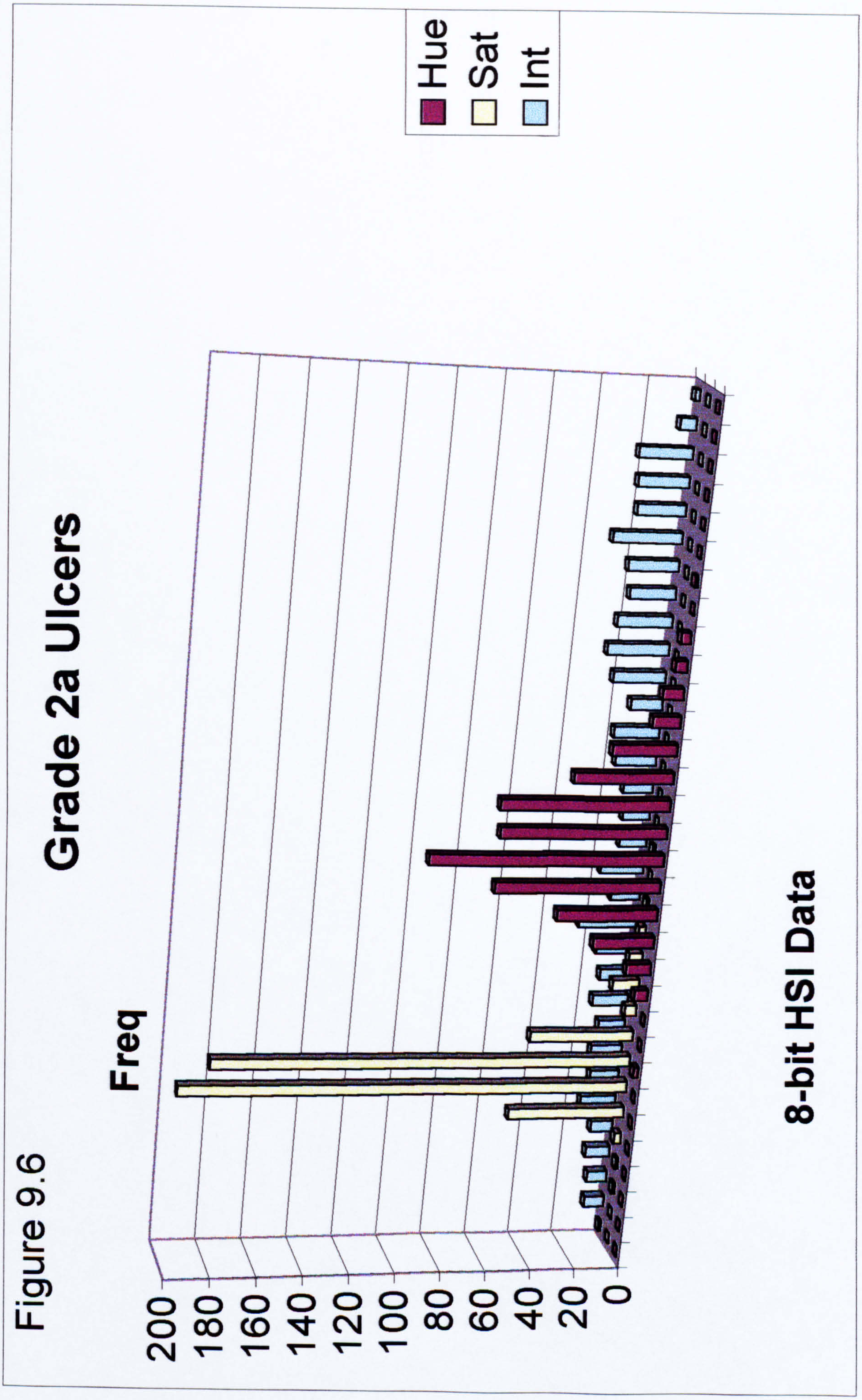

Grade 2a Ulcers
Freq
200
180
160
140
120
100
80
60
40
20
0
8-bit HSI Data
Hue
Sat
Int
Figure 9.6

Figure 9.7

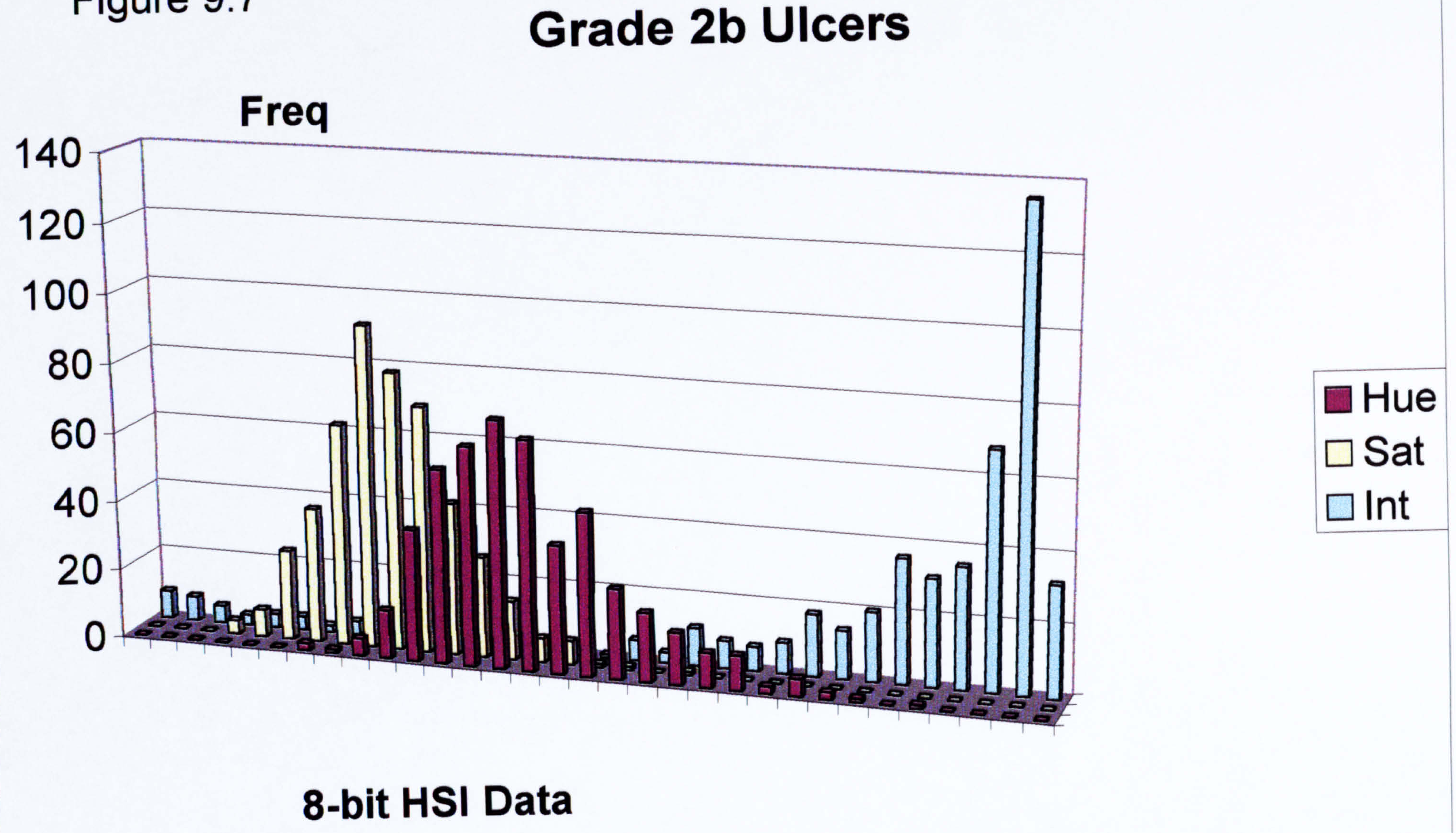

Grade 2b Ulcers
Freq
140
120
100
80
60
40
20
0
8-bit HSI Data
Hue
Sat
Int

Figure 9.8

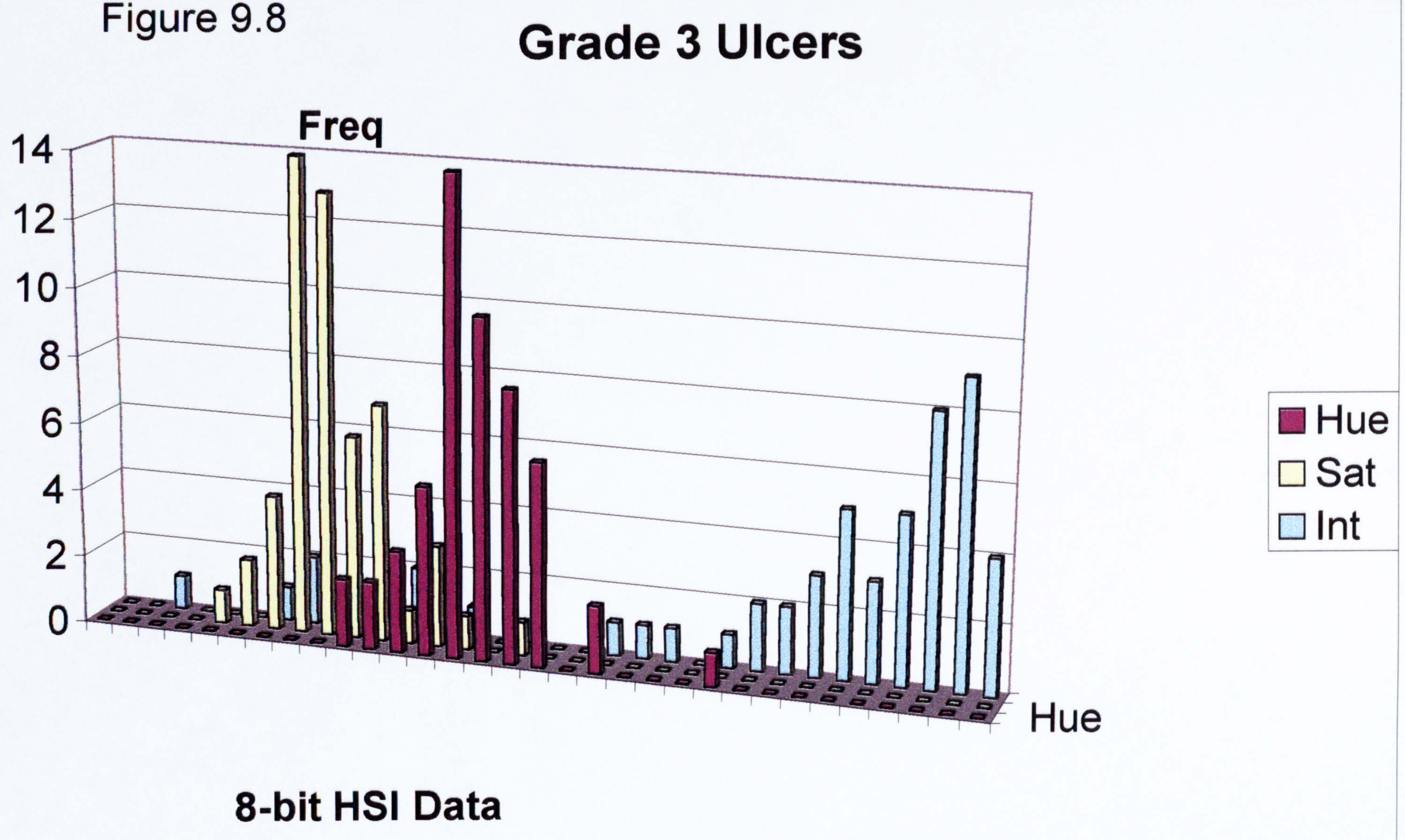

Grade 3 Ulcers
Freq
14
12
10
8
6
4
2
0
Hue
Hue
Sat
Int
8-bit HSI Data

Figure 9.9 **Radar Plot Grade 2b Ulcers**

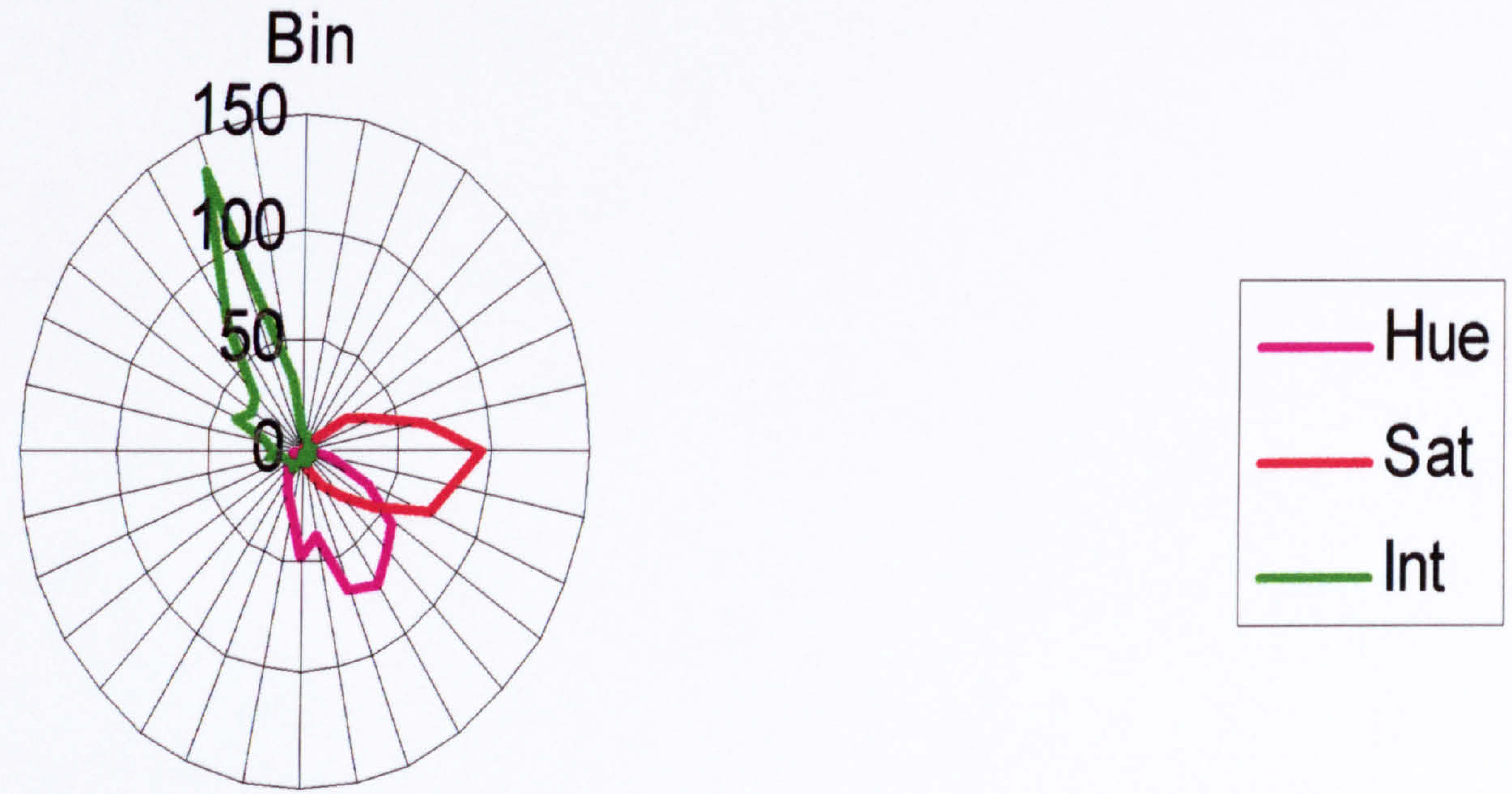


Figure 9.10

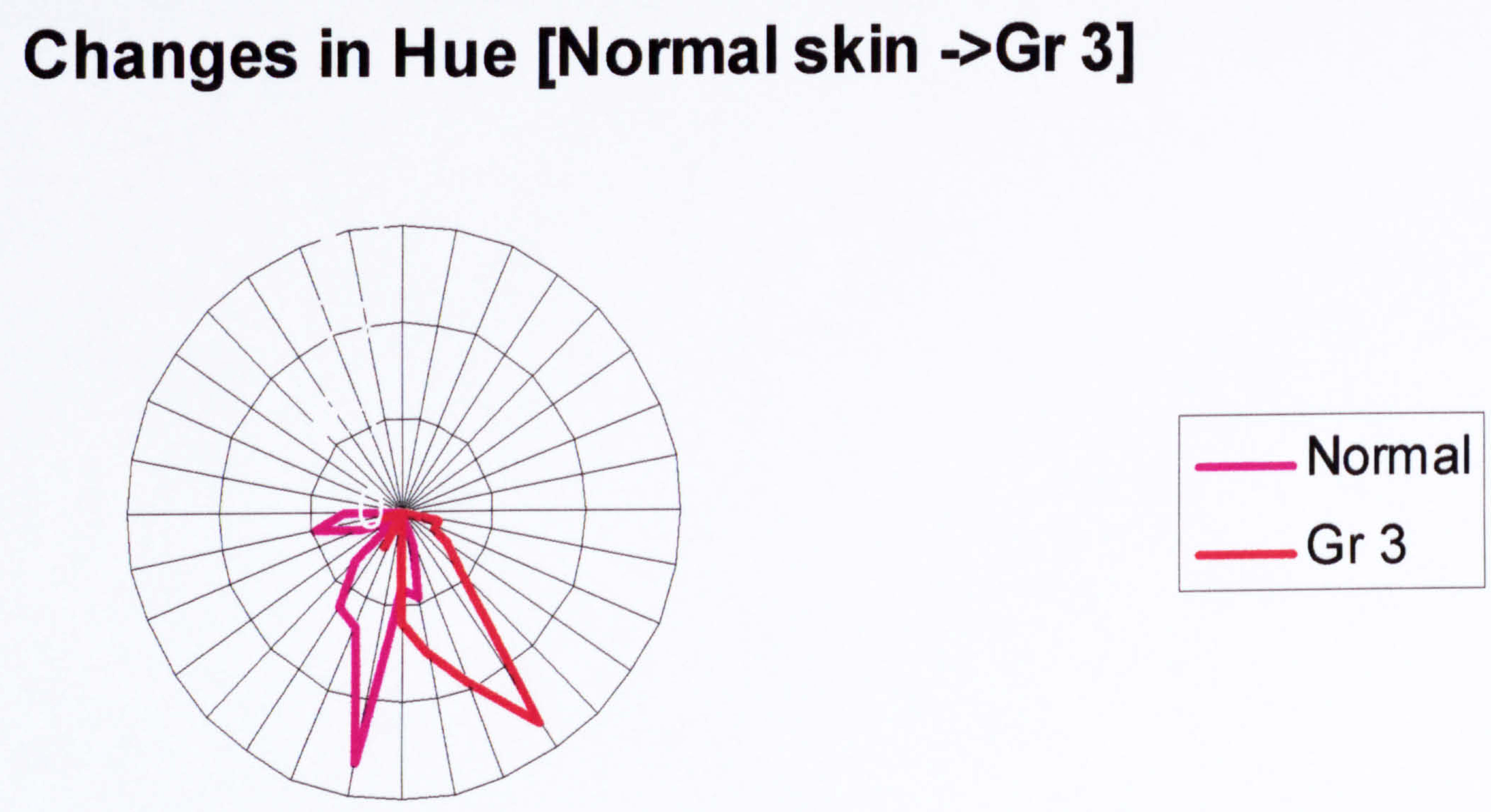


Figure 9.11

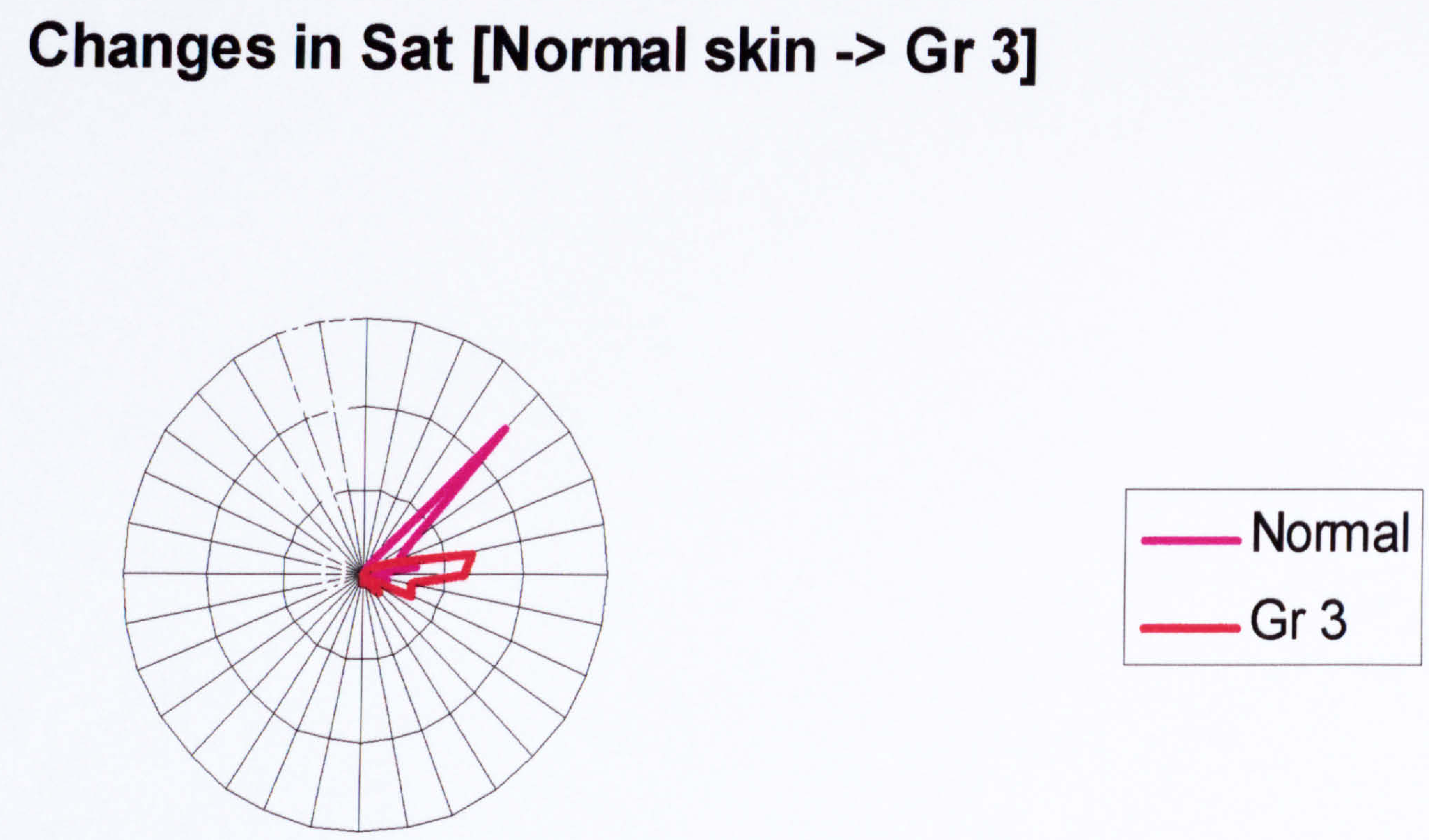
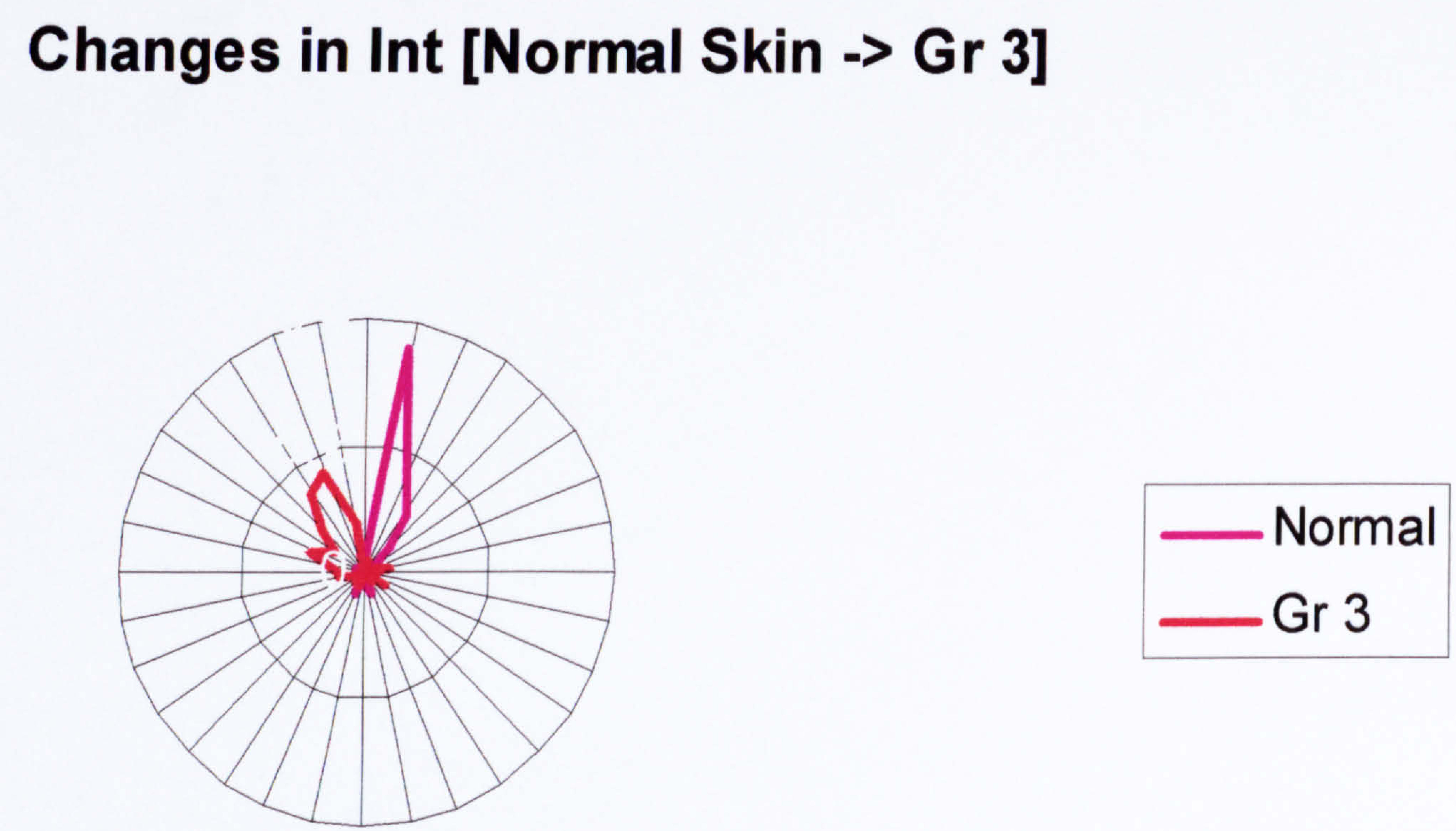


Figure 9.12



Using figure 9.13 data the differences were calculated between the 2b red ring and the green ring skin tone i.e. from the central point

	Ulcer Present	Ulcer Absent
Test Positive (i.e. in 2b ring)	29 (True Positives)	2 (False Positives)
Test Negative (in normal skin ring)	0 (False Negatives)	10 (True Negatives)

Sensitivity $\frac{29}{(29+0)}$ = 100%

Specificity $\frac{10}{(10+2)}$ = 83.3%

Further work with more data is indicated to determine the optimum screening cut offs.

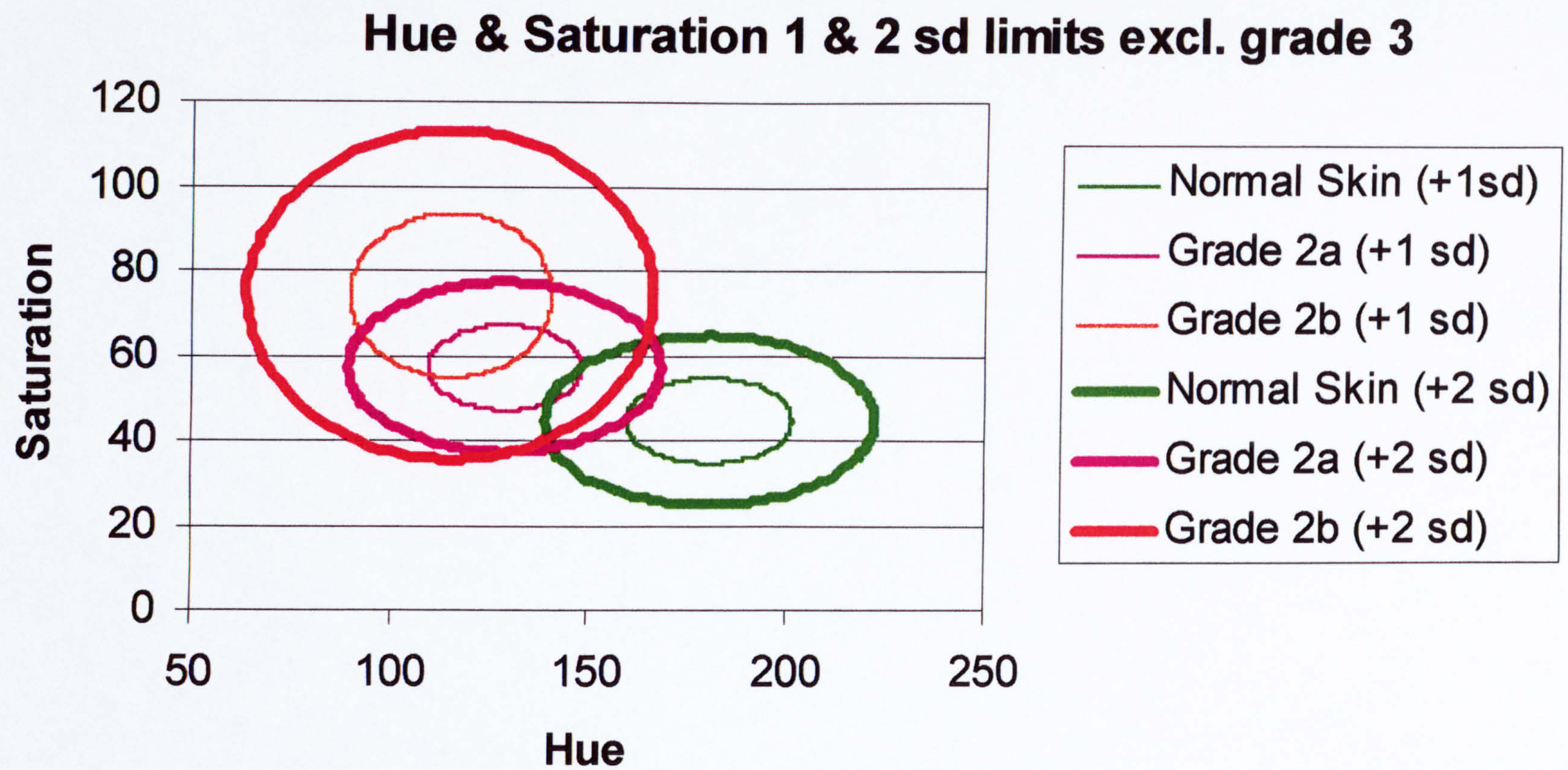
The ellipse demonstrated the std 1 and 2 normal, grade 2a and 2b has definite parameters. Thus the computer can identify early pressure ulcer formation with no disparity. A second ellipse using the information consensus panel, demonstrated a positive correlation between the computerized model and the panel's grades of pressure ulcers (see figure 9.14).

9.4 Discussion

Strengths of the study

The original population from which ellipses were derived from the other chapters included a large sample of 141 patients with sacral pressure ulcers

Figure 9.13


Hue & Saturation 1 & 2 sd limits excl. grade 3
Saturation
120
100
80
60
40
20
0
50
100
150
200
250
Hue
Normal Skin (+1sd)
Grade 2a (+1 sd)
Grade 2b (+1 sd)
Normal Skin (+2 sd)
Grade 2a (+2 sd)
Grade 2b (+2 sd)

which has demonstrated that there are distinct differences to be seen between normal skin tone and grade 2a ulcers and further difference with 2b when the skin has been broken. There is not such a distinct difference between grade 3 ulcers and grade 2b ulcers. This means that the model does detect when there is a break in the epidermis. Lyder (1991) outlines a grade 1 pressure ulcer as a skin area that ranges from pale pink to bright red in colour, a skin area that is non blanchable, skin that is warm to touch, skin with erythema that does not resolve within two hours, skin with oedema and skin area with intact dermis. It has been demonstrated that Hue saturation and intensity can be used to identify early grades of pressure ulcers and breaks in the epidermis.

Skin assessment is a key role in determining a patient's risk of developing a pressure ulcer. Observation of erythema should direct the nurse to consider if there are skin changes that are of normal physiology response or if they are abnormal, and the clinical importance of the assessment (Nixon and Gough 2001). The subsequent interventions and care provided will hopefully reverse the skin damage if undertaken promptly. There is a lack of clarity on whether redness should be persistent or transient. Furthermore, transient may be described as anything from 30 minutes to 48 hours (Versluysen 1986, IAET 1988 and Yarkony et al 1990). Nixon and Gough (2001) state that pathological and clinical symptoms of trauma/non blanching erythema with swelling and induration, can resolve without any superficial skin loss (Brooks and Ducan 1940, Lowthian 1994). This still requires further research as to how long these skin changes take to reverse or become a pressure ulcer.

It is essential that each nurse who assesses the patient pressure areas has a good knowledge of the classification system being used in their establishment in order to a assess their patients risk of pressure ulcers accurately.

The consensus panel provided the model with a gold standard on which to compare data. Further development, would be the equivalent of having the expert at the bedside to classify the skin. This would remove the necessity for a qualified nurse to carry out the skin assessment for pressure ulcers and would be very useful not just in hospitals but in primary care.

The argument on classification of pressure ulcers for research and auditing is plagued with dilemmas in achieving good inter rater reliability and validity of definition (Lyder 1991, Healey 1996).

This study could remove the issue of adoption of a national grading system as the statistical results of HSI demonstrate good reliability. A common classification would enable improved communication and documentation.

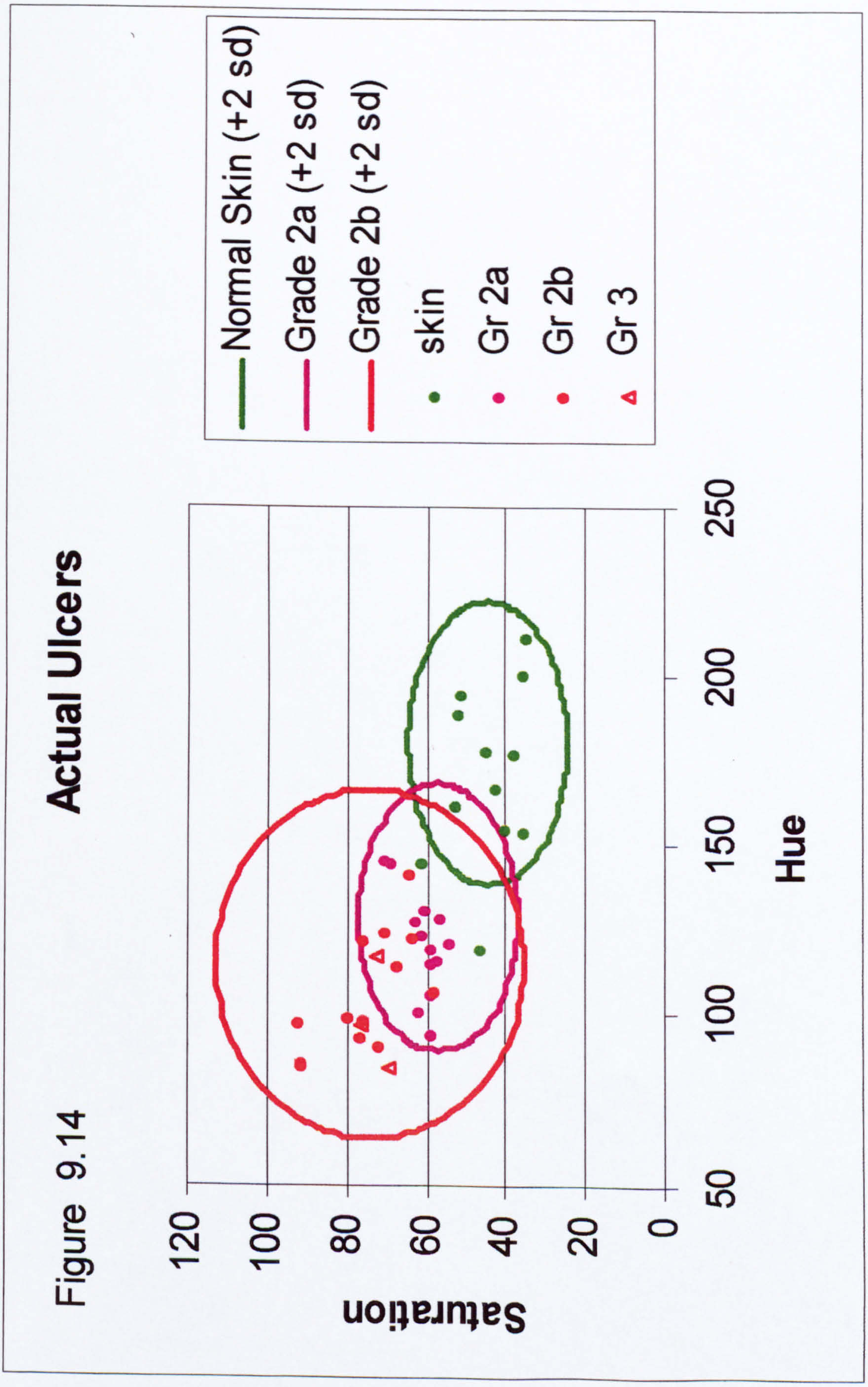

Actual Ulcers
Saturation
120
100
80
60
40
20
0
50
100
150
200
250
Hue
Normal Skin (+2 sd)
Grade 2a (+2 sd)
Grade 2b (+2 sd)
skin
Gr 2a
Gr 2b
Gr 3

Figure 9.14

Weaknesses of the study:

A limitation of the study was the sample size for the grade 3 ulcers was insufficient. The sample size was dictated by the number of patients recruited to the randomised clinical trial and therefore further work needs to be undertaken. The complexity of analysing data meant it was very time consuming and this may prohibit the use in day to day normal nursing. This model has only analysed sacral pressure ulcers and not heels due to the complexity of the photography on heels.

9.5 Conclusion

There is very little research to investigate the reliability and validity of classification systems. A computerised system removes the element of human error. Classifications of pressure ulcers are increasingly being used to measurable patient outcomes of care therefore, accurate classification will assist in this. Conversely, inaccurate grading of pressure ulcers could render league tables comparisons iniquitous. Incidence and prevalence data also uses classification of pressure ulcers and this can lead to more consistent collection of information. Correct classification of pressure ulcers would ultimately result in a higher standard of patient care and by preventing pressure ulcers by prompting nursing intervention. Accurate classification of pressure ulcers will give a measurable outcome in line with today's Health service culture of high quality.

9 5.1 Further work

♦ Study on heels ulcers to see this model works

♦ Prospective study of new data set against model

♦ Development of a probe that can measure blanching hyperaemia over a consistent time period and measured even pressure against the skin.

♦ To investigate whether a finding on the randomised clinical trial of Confor Med that 40% of patients with grade 1 pressure ulcer will proceed to a grade 2 pressure ulcer regardless of the surface they are placed on is correct.

♦ To investigate whether alternative statistical approaches e.g. likelihood ratio this interpretation could lead to improved sensitivity and specificity of the computerised model.

Chapter 10
10 Discussion

Chapter 10
Discussion

10.1 Discussion of Studies

10.1.1 Which is the best alternating mattress?

The primary aim of my study Randomised controlled trial of 141 Care of Elderly Patients who were assessed to have Torrance grade 2 and above pressure ulcers (71 on Cairwave, 70 on Nimbus 3) was to determine whether there were significant differences between the Pegasus Cairwave Therapy System & Proactive 2 Seating cushion and Huntleigh Nimbus 3 & Aura cushion. The secondary aim was to determine whether availability of extra pressure relief equipment would reduce the incidence of ulcers in an acute hospital. We used digital photographic recording of pressure ulcer development / progress as well as visual assessment of healing.

There was an overall improvement in sacral ulcers but no statistically significant differences between the two products tested. For heel-ulcers, there was a significant difference (P=0.019) with more patients healing on the Nimbus than on the Cairwave. The average length of stay of the patients who completed the trial was 21.6 days (Cairwave) and 21.7 days (Nimbus) for patients completing alive (range 1 –121 days) and 29.7 days (Cairwave) and 24.3 days (Nimbus) for patients who died. Routine hospital incidence monitoring showed that before the trial 0.2% of patients developed hospital-acquired pressure sores (Torrance grade 2+) but during the trial, the incidence dropped to 0.13%. Some of this may have been random due to increased nursing awareness the "*Hawthorn effect*" overall however, we concluded in the light these changes that the decrease in incidence was pressure relieving related. Thus, provision of extra pressure relieving equipment can reduce the incidence of pressure sores but may not influence length of stay.

In summary this first study thesis has demonstrated that:

- Both the Nimbus mattress and Cairwave therapy systems are effective treatments for pressure ulcers but since no placebo group was used, it is not possible to determine whether patients would have developed more pressure ulcers if they had remained on a standard mattress.

- Both mattress / cushion combinations provided an overall improvement in more than 90% of patients and healing of approximately 50% of sacral ulcers.

- The Nimbus mattress is significantly more effective for treatment of heel ulcers (55% healing) than the Cairwave therapy system (33% healing) [in line with the 20% difference chosen in the power calculation] but no differences were demonstrated for sacral ulcers.

- The average length of stay on either bed was approximately 21.5 days and therefore it appears that presence or absence of a ulcer did not affect the discharge of the patient. This is due to patients being discharged mainly into nursing homes.

- There was no clear difference between the mattresses or cushions for comfort scores. It appears if patients are asked by a non -biased /or an unbiased person they will say they are comfortable. This requires further investigation as it an important part of patient care.

- In informal surveys of nurses on the trial wards, we found no differences in the perceived nursing interventions required, nurse time required, dressings applied or equipment breakdown frequency.

- Overall the Nimbus 3 was the most cost effective mattress as it purchase price is cheaper than the Cairwave Mattress.

- Another important point when choosing which mattress should be compared: equipment failure rates, nursing interventions required (e.g. frequency of patient turning), etc. The number of repairs required for the Nimbus 3 was less and they only required yearly servicing. The nurses still turned patient every 4 hours despite the training and they mainly undertook this for patient comfort.

10.2.1 Which Alternating system heals faster?

The second study reported in this thesis is a more detailed analysis of the 141 patients assessed using computerised image analysis of the digital images of sacral ulcers captured during the trial. Healing rates were specifically discussed as well as other patient characteristics. Ninety-eight percent of ulcers examined were deemed superficial (Torrance grade 2a / 2b / 3). Precision of image analysis assessed by within- and between-batch Coefficients of Variation was excellent: Calibration CV 0.93 - 1.84%; Area CV 4.61 - 5.72%. The healing rates on the two mattresses were not shown to be statistically different from each other.

In our first paper (Russell et al, 2000 Chapter 6), we reported that the patients on each mattress type were broadly similar, in terms of age, Waterlow score, Burton score (Russell et al 1998 (a)), average and highest grade of ulcer present on admission to trial, and length of stay. There was no biases in terms of clinical reason for admission, mental state, or nutritional status. There was however, one area where a significant difference was demonstrated: incontinence. Significantly fewer patients on the Huntleigh Nimbus equipment were continent than those on Pegasus Cairwave equipment. These conditions would be expected to result in a greater incidence of pressure ulcers, but no significant trend was demonstrable, especially since the Nimbus 3 was that mattress which was statistically more effective for treating heel ulcers.

• The wound healing rates are interesting because the mean indicates that there is actually progression rather than regression, whilst the median indicates regression. This is the classic presentation of a skewed distribution in which despite trimming of gross outliers, a small number of poor results can give a false impression of the overall picture.

• Both mattresses overall promoted healing of grade 2a ulcers [as proven by the median healing rates]. There was a similarity of lack of progression or regression for grades 2b and there was no significant difference between healing rates on either mattress.

• We express confidence in our results because the precision of analysis was shown to be extremely good. In Clinical chemistry circles, analytical imprecision has long been considered important. In 1973 it was recommended that the maximum imprecision allowable for any assay in clinical use should be a between-batch Coefficient of Variation (CV) of 10% (Tonks, 1973) and further it was specified that any CV greater than 20% was medically useless (Elion-Gerritzen, 1980; Skendzel and Barnet, 1985). Computer image analysis therefore proved itself to be extremely effective, as the CV for wound area was no greater than 7%. Thus, our maximum 95% confidence limit for any measurement was 1.97 x 7%, or approximately ± 12%: a figure far better than would have been achieved by the 2-D rectilinear approximation method.

• Over the last ten years the use of computers has increased considerably, particularly in wound measurements. A tracing taken of the wound can be transferred onto a computer and the image can then be analysed automatically (Ahroni & Boyko, Brohannan 1983, Anthony 1985, Majeske 1992). Palmer *et al* (1989) used a camera linked to a computer to measure wound area. However, it was discovered that a camera angle of 20 degrees to the perpendicular resulted in a reduction of the measured area by approximately 10%. Thus care must be taken to standardise photographic technique.

- Analysis of wound healing rates in clinical trials is challenging: Healing was assessed by total area healed or percent area healed can be adversely influenced by the initial wound area depending on the method used for analysis it is possible to conclude that wound A heals faster than wound B, heals at the same rate or heals slower! Gorin et al (1996) see figure 10.1. Wounds tend to heal inwards from the outer edge, therefore, we utilised the linear growth of wound edge method suggested by Gorin et al (1996). One problem in wound margin length assessment is that wound margins are a fractal dimension: i.e. as one increases the precision of definition of the wound edge, the length continues to increase e.g. if the distance around an island can be measured as 1 mile, this can be increased by taking the measurement into every inlet and bay, and then around every rock - meaning that the true distance is actually impossible to assess.

Computer analysis is a simple and reliable way to accurately and reproducibly measure wounds. It has proved far more reliable than manual measurements, which had as much as 25% variation on repeat estimations between observers whereas computer measurements had less then 0.2% deviation on re-measurement (Mekkes J et al 1992). Data suggests that measuring the ulcer

Figure 10.1

Healing Rates Analysis

Wound A Wound B

Does wound A heal faster than wound B or at the same rate?

dimensions exudate and predominant tissue will provide the most valid indicators for monitoring the change in pressure ulcers over a time period. One of the major problems with trying to measure a wound is the natural curvature of the body as all the tools are designed to measure wounds as a flat object and consequently will be inaccurate (Plassman 1995). By using the modified Gorin et al (1996) method to calculate linear growth rate it was possible to gain the approximate the wound edges no matter how complex

• We measured the area of each wound and assumed that the wound was a perfect circle: by applying the formulae for the area of a circle (πr^2) the radius could be determined and then the formula for the circumference of a circle ($2\pi r$), the estimated linear wound margin was obtained. Incremental (7-day) and total wound area changes for each identified wound ($\Delta A = A_{initial} - A_{next}$) were calculated and the linear daily wound edge growth was calculated thus:

$$Wound\,\mathrm{Pr}\,ogression = \frac{\dfrac{\Delta A}{Circumference}}{TimeIncrement}$$

The calculation for wound progression gives a negative number for a reduction in wound area (healing) and a positive number for increase in wound area. Values are reported in mm/24 hours.

10.3.1 How good are nurses at classification of pressure ulcers?

My third study was a descriptive study using a questionnaire and twelve digital photographs classified by a consensus panel of experts using the European

Pressure Ulcer Advisory Panel and Stirling plus digits classifications. The expert panel comprised of 5 tissue viability specialists / clinical lecturers in tissue viability with many years of collective experience and examined 30 images over 2 ½ hours. In general consensus on wound grading was good with little argument. In only 2 images was there insoluble disagreement. Two hundred subjects were recruited from a Tissue Viability Society (N = 50), European Pressure Ulcer Advisory Panel (N=50), five Community Trusts (N=50) and five Acute Trust (N=50) in the England and Wales. The subjects were asked for demographic details (qualifications achieved, number of years qualified, employment grade and how their knowledge of classification of pressure ulcers has been obtained. The second part of the questionnaire asked them to classify twelve digital photographs of pressure ulcers against the European Pressure Ulcer Advisory Panel (EPUAP) and the Stirling plus digits.

• The study demonstrated that there is considerable lack of consensus when pressure ulcers are graded using the Stirling plus digit grading system, and less disagreement when the EPUAP scale is used.

• The study demonstrates that the statistical returns from different hospital and community units cannot be considered to be directly comparable. The lack of consensus on grades means that prevalence and incidence data collected for Health Authority and Primary Care groups will not be dependable. The Government believes league tables are helpful because by 'naming and shaming' poor performers, they can be encouraged to improve (Sunday Times 2001).

When performance data is as variable as our survey suggests, it becomes difficult to trust the raw data, and hence any league table derived from it. This problem has already been noted for pressure ulcer comparisons (Fletcher 1997). This indicates that the prevalence and incidence results currently collected by Trusts and government may contain considerable variations therefore, standardisation is required urgently.

- Furthermore, the study showed that the nurses most educated in pressure ulcer care (Clinical Nurse Specialists in Tissue Viability) were the most keen to receive extra education, whilst ward nurses were happy with their current knowledge and did not believe further education on pressure ulcers as opposed to education on other clinical problems was necessary.

- In the few previous studies of pressure ulcer grading, it has been recognised that photographs are not the ideal way to determine performance and that real life observations would be preferable, but since it is more practical to distribute images by post than patients, we used an image-based survey. This has the disadvantage that only one mode of examination (sight) is available to practitioners, and may mean that some of the discrepancies found maybe artefactual.

- The gold standard was for the original 'diagnosis' of pressure ulcer grade was not the opinion of a single tissue viability nurse but was a consensus opinion of 5 specialists. None of the previous studies have used the methodology.

• A National grading standard has been called for a number of years but as yet has not been agreed upon (Healey 1996, Harker 2000). When one has been agreed, it will require introduction with sufficient education to ensure that agreement is maximised. However we also advise caution. Pressure ulcer grading using a numerical system has some drawbacks: a grade 4 ulcer is not necessarily twice as bad, or twice as big or twice as anything as a grade 2 ulcer. It is possible that large 'low grade' ulcers may be upgraded to indicate the degree of clinical significance, and vice-versa for small 'high grade' ulcers.

• The only way to over come this problem may be to video a series of patients that grant their permission. The video recording would allow the assessor to see the wound and would allow better assessment of the pressure ulcer damage.

• The inability to calculate comparability statistics could be considered a weakness but is unfortunately unavoidable. However, we believe that the large discrepancy in accuracy Stirling and EPUAP (30.2% and 61.9% respectively) is adequate proof of superiority of the latter.

• The purpose of a grading system is to enable communication between professionals using a common scale on which it is believed like always equals like. Neither of the classification systems used in this study was completely reliable and accurate but the EPUAP system was simpler and more accurately used than the Stirling system but gives little clinical information. The significant variation demonstrated here indicates that the Stirling score fails to achieve the commonality of interpretation that is essential for meaningful comparison to be made.

10.4.1 Can hue saturation and intensity be used to classify pressure ulcers?

The fourth study used data from the original randomised control clinical trial of Pegasus Cairwave & proactive seating cushion and the Nimbus 3 & Aura seating cushion for the treatment of pressure sores. The trial collected data on 141 patients over a 19 month period . All grade 2 sacral pressure ulcers and above on the Torrance classification were photographed digitally. They were then analysed using a special macro (described in Chapter 6 and Russell et al Reynolds 2000). A pilot study consisted of 19 skin tones 19 grade 2a and 14 Grade 2b (using modified Torrance system. These were examined to determine whether there are any common factors relating HSI and a particular type of classification of pressure sores. The means and standard deviation of the skin tone, grade 2a and 2b pressure ulcers were plotted box plots.

A consensus panel consisting of four experts' opinion on the Hue saturation and intensity box plots and the images used to derive them were discussed in comparison to the European Pressure Ulcer Advisory Panel classification. Twelve photographs were then randomly selected for the nurse reliability postal questionnaire on the classification of pressure sores using Stirling plus digits and European Pressure Ulcer Advisory Panel.

In order to check the precision and accuracy of the camera and lighting, 10 arm and leg digital images were taken from four healthy volunteers. The digital images were taken under the same conditions as the trial patients. These images were then analysed using the special Macro, described early in chapter 6 using the rectangle box normally used for skin tone as the wound outline sequences. The sample population was 226 normal healthy volunteers, taken from the above study, 495 normal patient skin areas over the age 75, 510 grade 2a ulcers, 492 grade 2b ulcers and 53 grade 3 ulcers images. All images were analysed using image analysis data reported as an 8-bit number meaning that it has a range of 00000000 to 11111111 in binary which is equivalent to 0-255. At this point it was realised that traditional mean and ±sd statistics as used in the box and whisker plots did not function correctly. Hue saturation and intensity form constrained ranges with a wrap around of values being probable. This is a classic modulus arithmetic situation. Therefore, to calculate mean and ±sd for the data it was first necessary to examine the data to determine whether the mean value was on the 0-255 boundary or in the centre of the colour wheel. To demonstrate the construction of the data, radar plots were drawn showing the changes hue, saturation and intensity versus normal skin to grade 3 ulcers. If the distribution crossed the 255-0 boundary, the data was recentred to 128 by modulus addition, and the means and ±sd. Re calculated and the resultant mean was again recentred by modulus subtraction of 128. The ellipse demonstrated the std 1and 2 normal, grade 2a and 2b has definite parameter's. Thus the computer can identify early pressure ulcer formation with reasonable accuracy disparate. A second ellipse using the information consensus panel, demonstrated a positive correlation between the computerized model and the panel's grades of pressure ulcers

- The original population from which the ellipses were derived from the primary study of 141 patients with sacral pressure ulcers, which has demonstrated that there are distinct differences to be seen between normal skin tone and grade 2a ulcers and further difference with 2 b when the skin has been broken. There is not such a distinct difference between grade 3 ulcers.

This means that the model does detect when there is a break in the epidermis. Lyder (1991) outlines a grade 1 pressure ulcer as a skin area that ranges from pale pink to bright red in colour, a skin area that is non blanchable, skin that is warm to touch, skin with erythema that does not resolve within two hours, skin with oedema and skin area with intact dermis. It has been demonstrated that Hue saturation and intensity can be used to identify early grades of pressure ulcers and breaks in the epidermis.

• Skin assessment is a key role in determining a patient risk of developing a pressure ulcer. Observation of erythema should direct the nurse to consider if there are skin changes are of normal physiology response or abnormal, and the clinical importance of the assessment (Nixon and Gough 2001). The subsequent interventions and care provided will hopefully reverse the skin damage if undertaken promptly. There is a lack of clarity on whether redness should be persistent or transient. Furthermore, transient may be described as anything from 30 minutes to 48 hours (Versluysen 1986, IAET 1988 and Yarkony et al 1990). Nixon and Gough (2001) state that pathological and clinical symptoms of trauma/,non blanching erythema with swelling and induration, can resolve without any superficial skin loss (Brooks and Ducan 1940, Lowthian 1994). This still requires further research.

• It is essential that the nurses who are assessing the patient pressure areas have a good knowledge of the classification system being used by their establishment this method of assessing patient risk of pressure ulcers.

• The consensus panel provided the model with a gold standard on which to compare data. Further development, would be the equivalent of having the expert at the bedside to classify the skin. This would remove the necessity for a qualified nurse to carry out the skin assessment for pressure ulcers and would very useful not just in hospitals but in primary care.

• The argument about classification of pressure ulcers for research and auditing is plagued with dilemmas in achieving good inter rater reliability and validity of definition (Lyder 1991, Healey 1996).

• This study could remove the issue of adoption of a national grading system as the statistical results of HSI demonstrate good reliability. A common classification would enable improved communication and documentation.

10.2 Further work

10.2.1 Primary study Further work

The implications for clinical practice are immense the NHS is spending a large amount of money on pressure sore prevention / treatment but has no 'quality' evidence on which to base purchasing decisions. The Centre for Reviews and Dissemination states that overall it is impossible to determine the most effective surface for treatment or prevention of pressure ulcers. More Randomised trials need to be undertaken to produce the required evidence, but this requires considerable input of resources from research grants, the health service, and manufacture's. There is significant 'wastage' of recruits into trials in order to gain the necessary patient sample size. The NICE guidelines Clinical Governance and Essence Care are all focusing on the pressure ulcer incidence as outcome measures of patient care. More research to investigate patients comfort whist on specialised mattress is essential as hard mattresses may mean that a patient will not comply with the therapy as they find it uncomfortable.

10.2.2 Second study Further work

The Gorin modified method using a the macro was very problematic as there are many stages involved to gain the measurements therefore, it is not ideal for daily use and is restricted to research projects due to it complexity. More trials are required on wound measurement as many of the wound care products currently used, the efficacy of these are unknown. NICE 2001 Guidance on the use of debriding agents and specialist wound care clinics for difficult to heal surgical wounds states that " *very few studies measures healing rates as an outcome*". The modified Gorin et al (1996) method provides daily healing rates and would give an easy estimation of the effectiveness of healing rates in a sufficiently powered study. This would then enable more cost effective wound care and have great economic impact to the patient care and to the health service.

10.2.3 Third study Further work

Classification of pressure ulcers is not easy and consequently a simple grading system such as EPUAP generates more consensus than a complex system. However, if one were to consider that this demonstrates that EPUAP is 'better' than the Stirling system, it still does not demonstrate that it is the 'best' grading system as there are many alternatives that have not been considered. Further research to develop an 'ideal' system would be required, if a national system is thought desirable.

Clinical Nurse Specialists in tissue viability are highly educated but believe they should continue to learn pressure ulcer grading. More training is required for Nurse Specialist and this demand should be met by the Tissue Viability Society or European Pressure Ulcer Advisory Panel so standardisation is achieved. Any grading system must be cascaded down to the nurses at ward level to enable auditing particularly with reference to Clinical Governance and Essence of Care (2001) National Institute for Clinical Excellence Pressure ulcer risk assessment and prevention.

The reluctance expressed towards more education on pressure ulcer grading at ward level may in the future hinder change and introduction of yet another different grading system in the future. Once a system has been selected, it is important that appropriate training is given to the users (Fletcher 1995). Documentation presented in a clear and legible format using diagrams and text is helpful. Training should not just occur once but follow up sessions should be organised, e.g. mandatory updates.

Classification of pressure ulcers can be monitored by regular evaluation, particularly through link nurses, when prevalence audits are undertaken on a yearly basis.

Furthermore, the site of an ulcer may have clinical significance. The study model attempted to synthesise all of these features into a grading system. However, as we have demonstrated this does not work and leads to imprecision.

Further research to investigate mis-reporting of current grades, non-numerical scales, the importance of superficial and full-thickness lesions and the significance of blanching / non-blanching erythema may all shed light on this complex area.

Although a perfect grading system may be impossible to achieve, we need to continue to work towards understanding what a grading system should provide and how this can be achieved. Nixon (2001) states that multifactorial nature of pressure ulcers and tissue breakdown is extremely complex and is individual to each patient skin response. All these factors need to be integrated into a classification system and tested for reliability, validity, sensitivity and specificity.

10.2.4 Fourth study Further work

A large study does need to be repeated on heel ulcers to see if this model works, particularly as heels ulcers develop quickly and deteriorate so rapidly to a necrotic stage where there is poor circulation in the elderly patients.

A large prospective study of using a new data to compare it against the study model to repeat it's efficacy and reliability. Particularly as the sensitivity was 100% and the specificity 83.3%.

The development of a probe that can measure blanching hyperaemia over a consistent time period and can measure even pressure against the skin.

To investigate whether a finding on the randomised clinical trial of Confor Med that 40% of patients with grade 1 pressure ulcer will proceed to a grade 2 pressure ulcer regardless of the surface they are placed on is correct.

To investigate whether alternative statistical approaches e.g. likelihood ratio interpretation could lead to improved sensitivity and specificity.

The ultimately achievement would be to classify a early pressure ulcer and provide the optimum equipment to reverse skin damage.

This thesis has demonstrated that the all hypotheses tested are true and that computer image analysis can be used to make prognostic assessment of an early pressure ulcer. This model requires further exploration to develop it into a user tool that all nurses can use in every day practice. This could have a great economic impact on the continually rising cost of treating pressure ulcers. Incidence and prevalence figures would become accurate adding more credibility to the Tissue Viability field. Clinical Governance, bench marking, and NICE would be provided with standardised figures. Ultimately a higher standard of patient care will ensue as avoidance of from the pain and discomfort of suffering a pressure ulcer will transpire.

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Appendix 1

Appendix 1

Volunteer Assent form Randomised Clinical Trial of Pegasus Cairwave and Huntleigh Nimbus 3

The research nurse has given me a copy of the information sheet. I have read and understood the sheet and had an opportunity to raise concerns and questions I may have with the research nurse.

I understand that I may withdraw from the study at any time I choose without having to give reason. This will not influence my medical treatment in any way.

I give my consent to be included in this clinical trial. I give my permission for photographs to be taken related to the trial. I also give permission for the photographs to be used in articles related to the research and any subsequent publication/lectures.

All information will be kept confidential. Photographs will only be identifiable by the trial number, in order to ensure my anonymity.

Patients signature...

Date...................

Witness signature*..

Date....................

*Witness may be the trial or ward nurse

Appendix 2

3. Why do you need photographs?
Pressure sores get better very slowly and it is difficult for anyone to remember what every pressure sore in the hospital looks like. Therefore to prove that sores are healing and to measure how quickly this is happening, we are taking photographs using a special camera so that we can get a computer to analyse the pictures. The pictures will be taken very carefully so that no-one will be able to identify you from the photograph.

4. What if I don't want to take part?
You do not have to be in the trial! If you do not want to take part, you will be given the normal treatment that you need. This may well mean that you are given one of the special mattresses anyway! There is no compulsion to take part - Do not feel guilty that you are letting us down - Our first aim is to help make you better.

5. Who do I ask if I want to know more?
The nurses on the ward will be happy to answer your questions but if there is anything you want to know that they cannot tell you, our Tissue Viability Nurse Specialist (Linda Russell), who is running the trial, will be happy to see you.

Thank you for your help.

Appendix 2

BURTON HOSPITALS

Randomised Clinical Trial of

Pegasus Cairwaves

and

Huntleigh Nimbus 3.

Information for Patients

Lead Investigator:

Linda Russell (Tissue Viability Nurse Specialist)

Randomised Clinical Trial of Pressure Relieving Mattresses and Seat Cushions

We are currently running a clinical trial comparing two types of special mattresses used to treat patients with pressure sores (bed sores). The nurses have identified you as someone who may benefit from this type of special treatment. We therefore would like to ask you if you would be prepared to assist us with our research.

What We Will Ask You to Do.
There is very little you need to do to help us. If you agree to take part in the trial you will be treated just the same as any other patient but you will be allocated a special mattress and seat cushion specifically for you. All we ask is that after a few days, you to tell us what you think about the comfort of the special mattress and seat cushion and that you allow us to record your pressure sores by taking photographs.

Before you enter the trial you (or a relative) will be asked to sign a consent form to say that we have explained the trial to you and that you are happy to participate.

Questions you might ask about the trial?

1. Why Are You Trying Out These Special Mattresses?
The NHS spends millions of pounds a year on special equipment to stop patients getting bed sores, BUT no-one has yet done any good research to show that these special mattresses do anything to help. We are doing the research that the NHS needs to be able to make a decision about whether it is spending its money wisely.

2. Why Are You asking Me to Help?
We are asking anyone who has a pressure sore if they will help us because we need at least 150 patients to try each type of bed, to prove whether one type of bed is better than another. On average each patient stays on one of these beds for about 2 weeks so if we are to get enough patients during the year of the trial, everyone who has a pressure sore is asked if they will participate.

Appendix 3

```
        PC_Image:136              1 {Interactive file open}
        PC_Image:ca                 {Open}
        PC_Image:270e             2 {Record Input File Format}
        PC_Image:270f F:\2171509S.TIF {Record Input File name}
        PC_Image:10a                {Convert to HSI}
        PC_Image:107  Draw calibration line  {Prompt for user}
        PC_Image:74                 {Calibrate pixels}
       Calibrate:67               0 {XY cursor}
       Calibrate:1ca              1 {Switch Interactive}
        PC_Image:107  Draw whole + skin (Close, Autofill) {Promp
t for user}
        PC_Image:6e                 {Binary Editor}
          Binary:1ca              1 {Switch Interactive}
        PC_Image:1cd                {Select result binary}
        PC_Image:7e                 {Copy Binary Image}
        PC_Image:1cc                {Select result binary}
        PC_Image:77                 {Clear Binary Image}
        PC_Image:107  Draw crater + tail (No close, no autofill,
 2) {Prompt for user}
        PC_Image:6e                 {Binary Editor}
          Binary:1ca              1 {Switch Interactive}
        PC_Image:c4                 {BINARY : Morphology Operator
s}
          Binary:e5               1 {Passes}
          Binary:de               0 {Dilate binary}
          Binary:1                0 {Quit}
        PC_Image:1b9                {Select original binary}
        PC_Image:b0                 {BINARY : Logical Operators}
          Binary:d9               0 {Logical: XOR binaries}
          Binary:d7               0 {Logical: AND binaries}
          Binary:1                0 {Quit}
        PC_Image:1b8                {Select original binary}
        PC_Image:107  Save binary {Prompt for user}
        PC_Image:136              1 {Interactive file open}
        PC_Image:73                 {Save}
        PC_Image:270e             1 {Record Output File Format}
        PC_Image:270f C:\PC_IMAGE\IMAGES\2171509S.IMF {Record Ou
 tput File name}
        PC_Image:c8                 {Select Measurements}
          Select:134              1 {Grey Weight}
          Select:135              1 {Opt. Weight}
          Select:144              4 {Feret? ( ) }
          Select:1                0 {OK}
        PC_Image:136              1 {Interactive file open}
        PC_Image:68                 {Measure all objects}
        PC_Image:270f C:\PC_IMAGE\IMAGES\ANDY.FDT {Record Output
  File name}
        PC_Image:136              1 {Interactive file open}
        PC_Image:67                 {Histogram all objects}
```

Appendix 3

```
        PC_Image:270f C:\PC_IMAGE\IMAGES\ANDY.DAT {Record Output
File name}
        PC_Image:1cd                    {Select result binary}
        PC_Image:77                     {Clear Binary Image}
        PC_Image:1cc                    {Select result binary}
        PC_Image:77                     {Clear Binary Image}
        PC_Image:107  Enter required area for skin tone  {Prompt
for user}
        PC_Image:6e                     {Binary Editor}
          Binary:1ca                  1 {Switch Interactive}
        PC_Image:136                  0 {Interactive file open}
        PC_Image:68                     {Measure all objects}
        PC_Image:136                  1 {Interactive file open}
        PC_Image:c3                     {Save}
        PC_Image:270f C:\PC_IMAGE\IMAGES\ANDY.TXT {Record Output
File name}
        PC_Image:7a                     {Close Measures file}
        PC_Image:1cd                    {Select result binary}
        PC_Image:1cc                    {Select result binary}
        PC_Image:77                     {Clear Binary Image}
        PC_Image:78                     {Clear Binary Image}
```

Appendix 4

CLASSIFICATION OF PRESSURE ULCERS QUESTIONNAIRE

1. On which area do you work?
   - A. Clinical nurse specialist ☐
     Tissue viability ☐
   - B. Community ☐
   - C. Acute hospital ☐
   - D. Pressure ulcer advisory panel

2. Which qualification do you hold?...

3. Which grade are you?
   - A. D ☐
   - B. E ☐
   - C. F ☐
   - D. G ☐
   - E. H ☐
   - F. I ☐

3. How many years have you been qualified?
   - A. Less than one ☐
   - B. One to two ☐
   - C. Three to four ☐
   - D. Four to five ☐
   - E. Five to ten ☐
   - F. More than ten ☐

5. Have you undertaken any post basic training on the classification of pressure ulcers?

   YES ☐
   NO ☐

   If yes please give details...

   ....

   ....

6. Do you consider your knowledge on grading of pressure ulcers to be?

- Excellent ☐
- Good ☐
- Fair ☐
- Poor ☐

7. Would you like to have additional training on classification Systems?

- YES ☐
- NO ☐

8. Where did you gain your education of classification of pressure Ulcers?

- A. Study day ☐
- B. Journals ☐
- C. Academic courses ☐
- D. Tissue Viability course ☐
- E. Other colleagues ☐

9. When was the last time you read an article on classification of pressure ulcers

- A. Less than one month ☐
- B. One-three months ☐
- C. Four to six months ☐
- D. Four to twelve months ☐
- E. Over twelve months ☐

10. Which journals do you regular read to obtain up-to-date information in tissue viability/pressure ulcer prevention?

- A. British Journal of Nursing ☐
- B. Nursing Times ☐
- C. Professional Nurse ☐
- D. Journal of Advanced Nursing ☐
- E. Journal of Wound Care ☐
- F. Journal of Tissue Viability ☐
- G. Nursing Standard ☐

11. Which of the following do you think most contributes to your knowledge of the classification of pressure ulcers

A. Journals ☐
B. Books ☐
C. Tutors ☐
D. Medical staff ☐
E. Post registration courses ☐
F. Other nurses ☐
G. Others – Please specify ☐

12. Are you happy with your current level of knowledge on the classification of pressure ulcers?

Yes ☐
No ☐

13. What topics would you like to learn more about on the classification of pressure ulcers? Please state

....
....
....
....
....

14. Which grading system do you currently use?

A. Stirling ☐
B. Torrence ☐
C. David ☐
D. National Ulcer Advisory Panel ☐
E. Other. Please state ☐

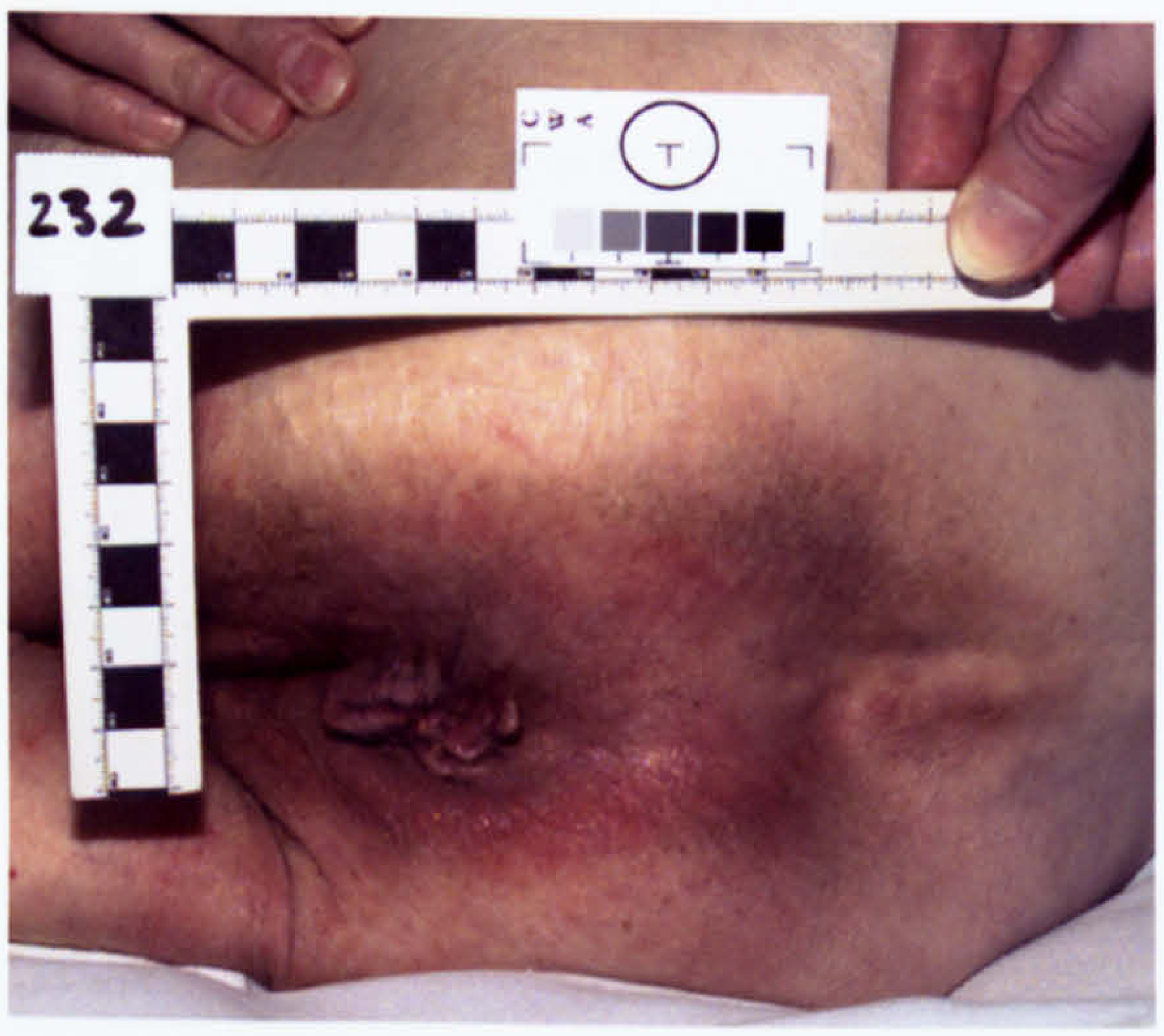
14. Do you believe that a national grading system needs to be adopted?

Yes ☐
No ☐

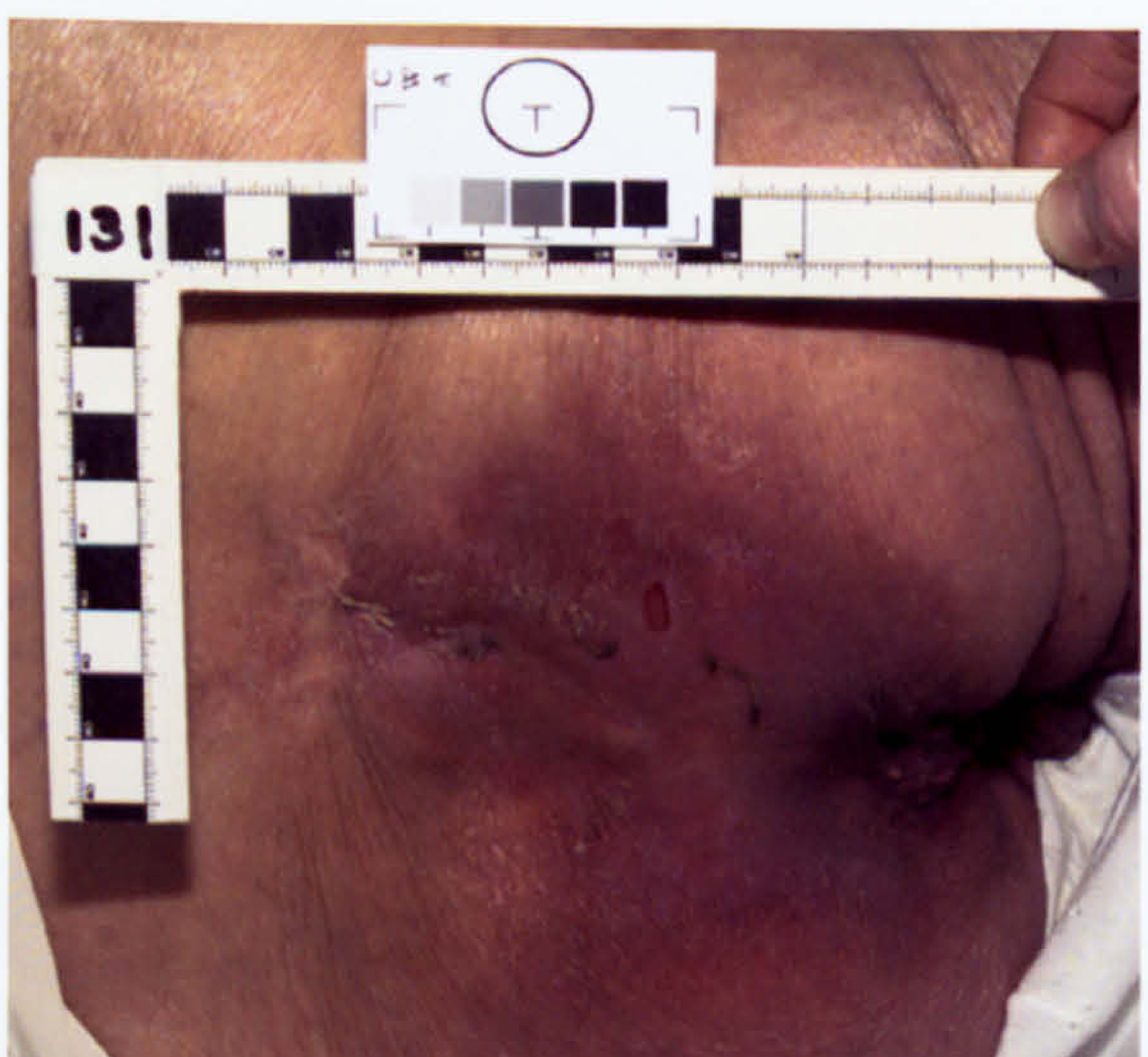
Thank You! for completing the first part of the questionnaire. Now continue with the grading exercise using the two classifications systems provided and put the answers to the photographs on the sheet provided. Please return in the stamp address envelope.

A

B

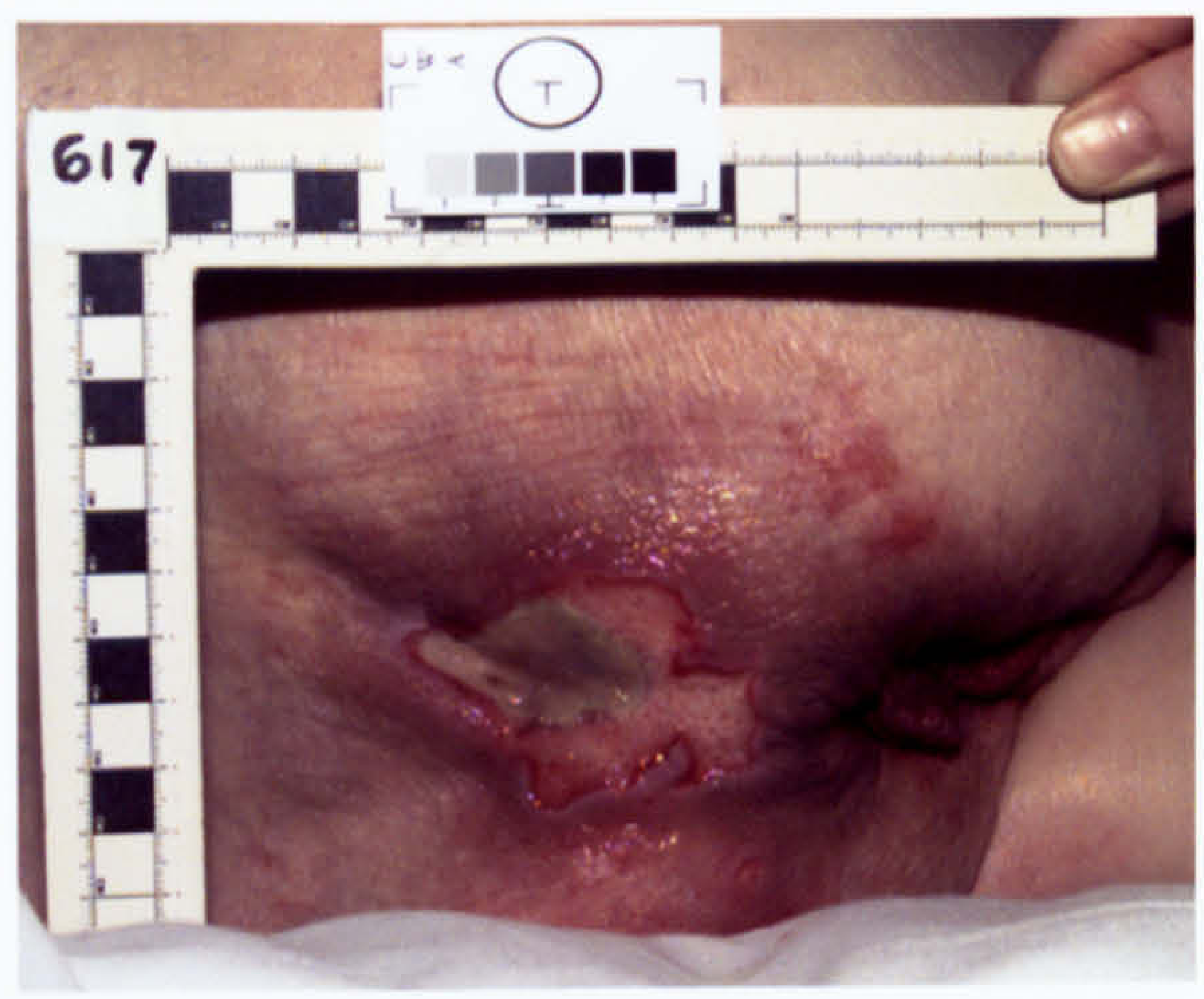


C



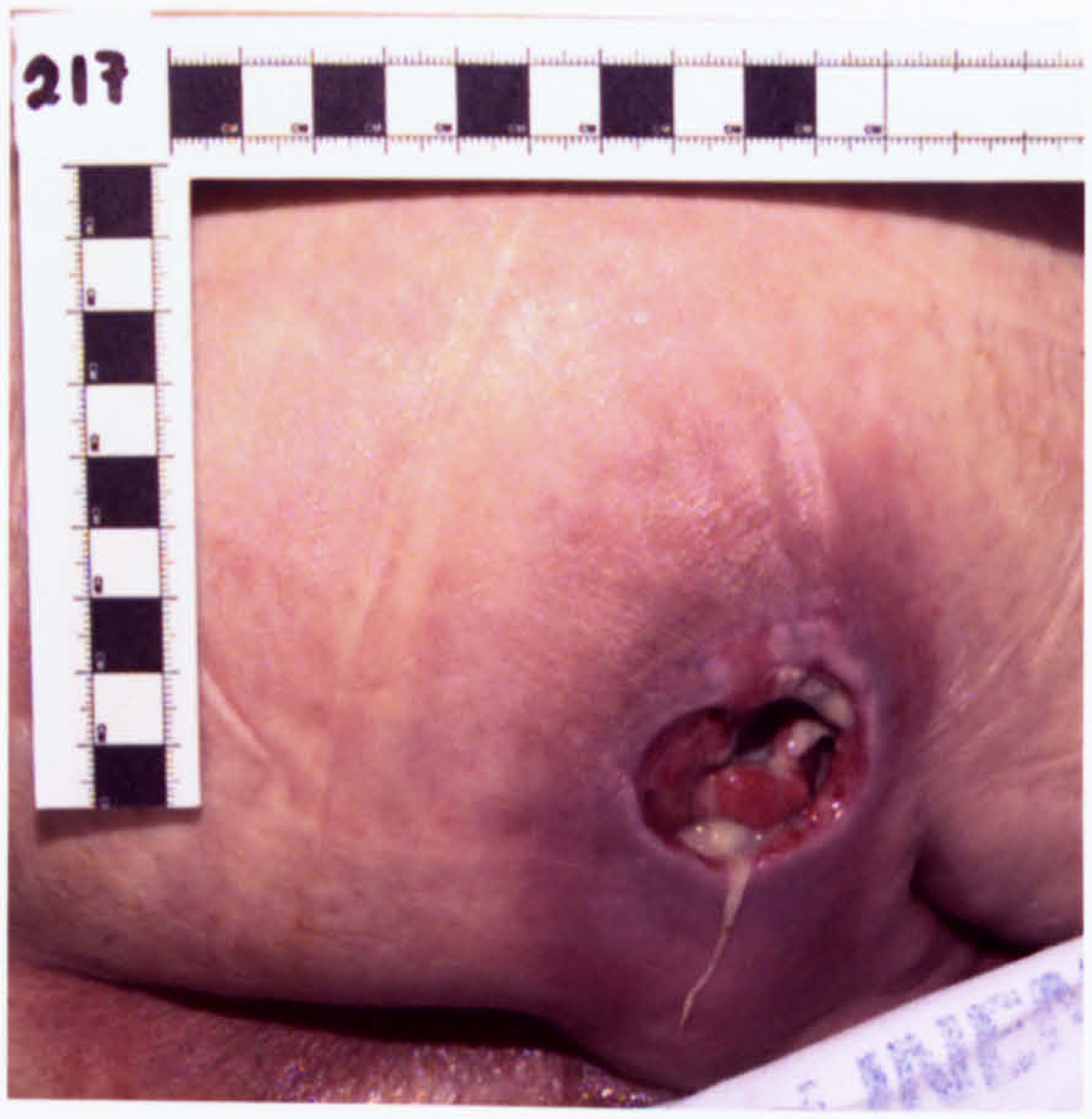
D

E



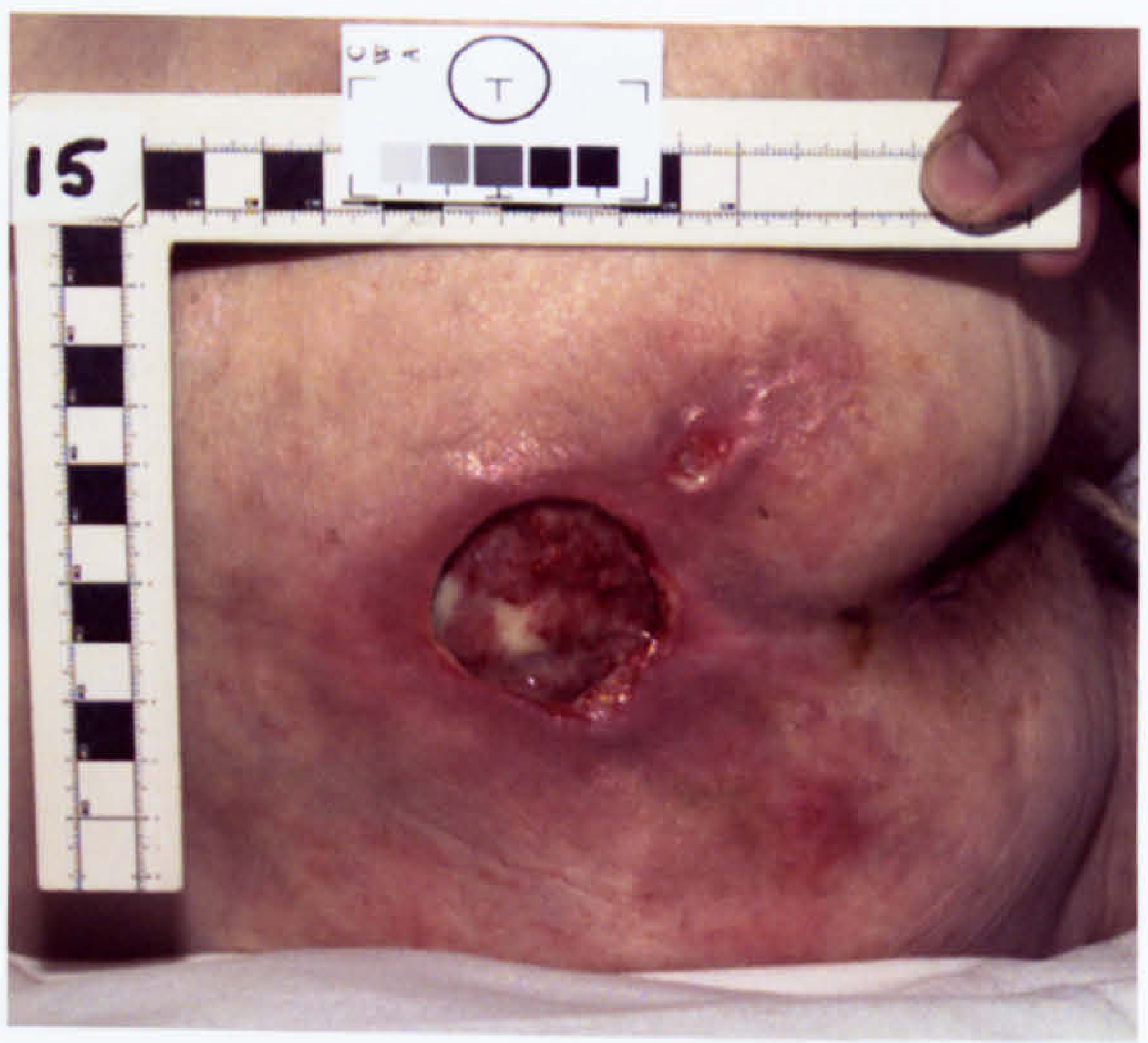
F

G



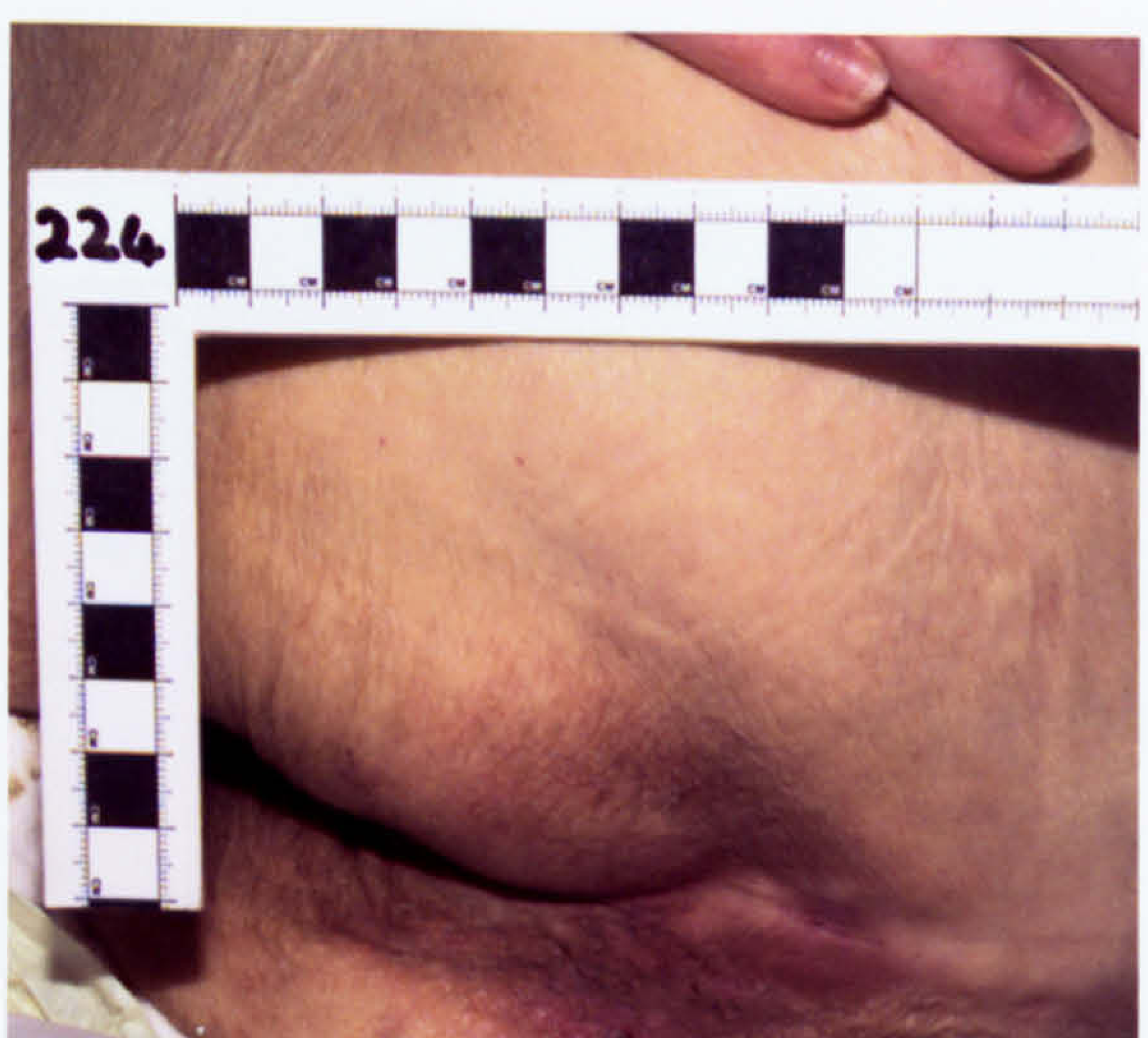
J

H



K

I



L

<u>Photograph Classification of Pressure Ulcers</u>

A Stirling grade...................

European Pressure Ulcer Advisory Panel......................

B Stirling grade...................

European Pressure Ulcer Advisory Panel......................

C Stirling grade...................

European Pressure Ulcer Advisory Panel......................

D Stirling grade...................

European Pressure Ulcer Advisory Panel......................

E Stirling grade...................

European Pressure Ulcer Advisory Panel......................

F Stirling grade...................

European Pressure Ulcer Advisory Panel......................

G Stirling grade...................

European Pressure Ulcer Advisory Panel......................

H Stirling grade...................

European Pressure Ulcer Advisory Panel......................

I Stirling grade...................

European Pressure Ulcer Advisory Panel......................

J Stirling grade...................

European Pressure Ulcer Advisory Panel......................

K Stirling grade...................

European Pressure Ulcer Advisory Panel......................

L Stirling grade...................

European Pressure Ulcer Advisory Panel......................

Photograph Classification of Pressure Ulcers

A Stirling grade...3.2................

European Pressure Ulcer Advisory Panel...........4...........

B Stirling grade......1.2..............

European Pressure Ulcer Advisory Panel...........1...........

C Stirling grade...2.2 x.x3................

European Pressure Ulcer Advisory Panel.........1.............

D Stirling grade......3.4 x.x3.............

European Pressure Ulcer Advisory Panel.........3.............

E Stirling grade......2.4 x.x3.............

European Pressure Ulcer Advisory Panel............2...........

F Stirling grade...2.2x.x3................

European Pressure Ulcer Advisory Panel...2...................

G Stirling grade...3.4 x.xx1.....

European Pressure Ulcer Advisory Panel... 3...................

H Stirling grade......3.2x.x3.............

European Pressure Ulcer Advisory Panel......3................

I Stirling grade...2.2................

European Pressure Ulcer Advisory Panel...2...................

J Stirling grade......3.4 x.x3.............

European Pressure Ulcer Advisory Panel.........3.............

K Stirling grade......2.1x.x2.............

European Pressure Ulcer Advisory Panel.........2.............

L Stirling grade......3.4x.x4.............

European Pressure Ulcer Advisory Panel......1or3................

Appendix 5

Physiology of the skin and prevention of pressure sores

Linda Russell

Abstract

Historically, pressure sores have been seen as a nursing problem, and still are to a certain extent today. Nurses therefore need to have a comprehensive understanding of the physiology of the skin to assist them in preventing and treating pressure sores. Despite a great deal of research on the aetiology of pressure sores, their origins are still not fully understood. This article discusses the physiology of the skin and the aetiology of pressure sores. Influences on pressure sore development are multifactorial and tend to be divided into three main categories: extrinsic (e.g. environmental pressure, shear and friction), intrinsic (e.g. general health, age, mobility, body weight, incontinence and nutrition), and external factors (e.g. long trolley waits in accident and emergency departments or before admission following a long period collapsed on the floor, hard chairs, and immobilization with traction).

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Prevention of pressure sores has always been a nursing role. Florence Nightingale believed that pressure sores could be prevented by good nursing care (Abel-Smith, 1960), and doctors have always regarded pressure sores as a nursing problem; indeed, Charcot considered that 'doctors could do nothing about them' (Dealey, 1991). These attitudes have resulted in nurses carrying the burden of treating pressure sores, rather than attempts being made to establish and eliminate the cause of the problem.

Table 1. The main functions of the skin

Maintenance of the body's temperature through vasodilatation and constriction of the surface blood vessels
Protection from friction and shear, dehydration, ultraviolet light and radiation
Perception of temperature, pain and touch
Excretion of small amounts of salts and perspiration (aids thermal regulation)
Synthesis of vitamin D
Prevention of loss of water and electrolytes

The key to successful prevention is the relief of pressure. There is sound practical sense in the adage: 'You can put anything on a pressure sore except the patient' (Witkowski and Parish, 1986). Nurses deliver skin care and assist in meeting patients' hygiene needs. This provides them with the ideal opportunity to assess the patient's skin condition and so determine whether pressure-relieving equipment is required.

An understanding of the physiology of the skin is essential to comprehension of the development of pressure sores. The aetiology of pressure sores is multifactorial. Despite a great deal of research, the mechanism and circumstances under which they occur are still not fully understood.

PHYSIOLOGY OF THE SKIN

The skin is a complex organ and one of the largest organs in the body. It can reflect a person's state of health, e.g. a flushed skin will indicate a temperature whereas a pale skin will indicate shock or general malaise.

The surface area of the skin of an average adult is 1.8 m^2. It varies in thickness depending on the requirements of the particular area of the body; the thickest skin occurs on the soles of the feet and the palms of the hands (Collins, 1998). The main functions of the skin are listed in *Table 1*.

The skin comprises two principal layers: epidermis and dermis (*Figure 1*).

Epidermis

The epidermis is composed of stratified squamous epithelium, keratinocytes, melanocytes, Langerhan cells and Granstein cells (which are associated with immunity) (Tortora and Anagnostakos, 1987). It may be subdivided into five layers, as follows:

1. ***Stratum basale:*** This is the deepest layer of the epidermis. It consists of basophilic colum-

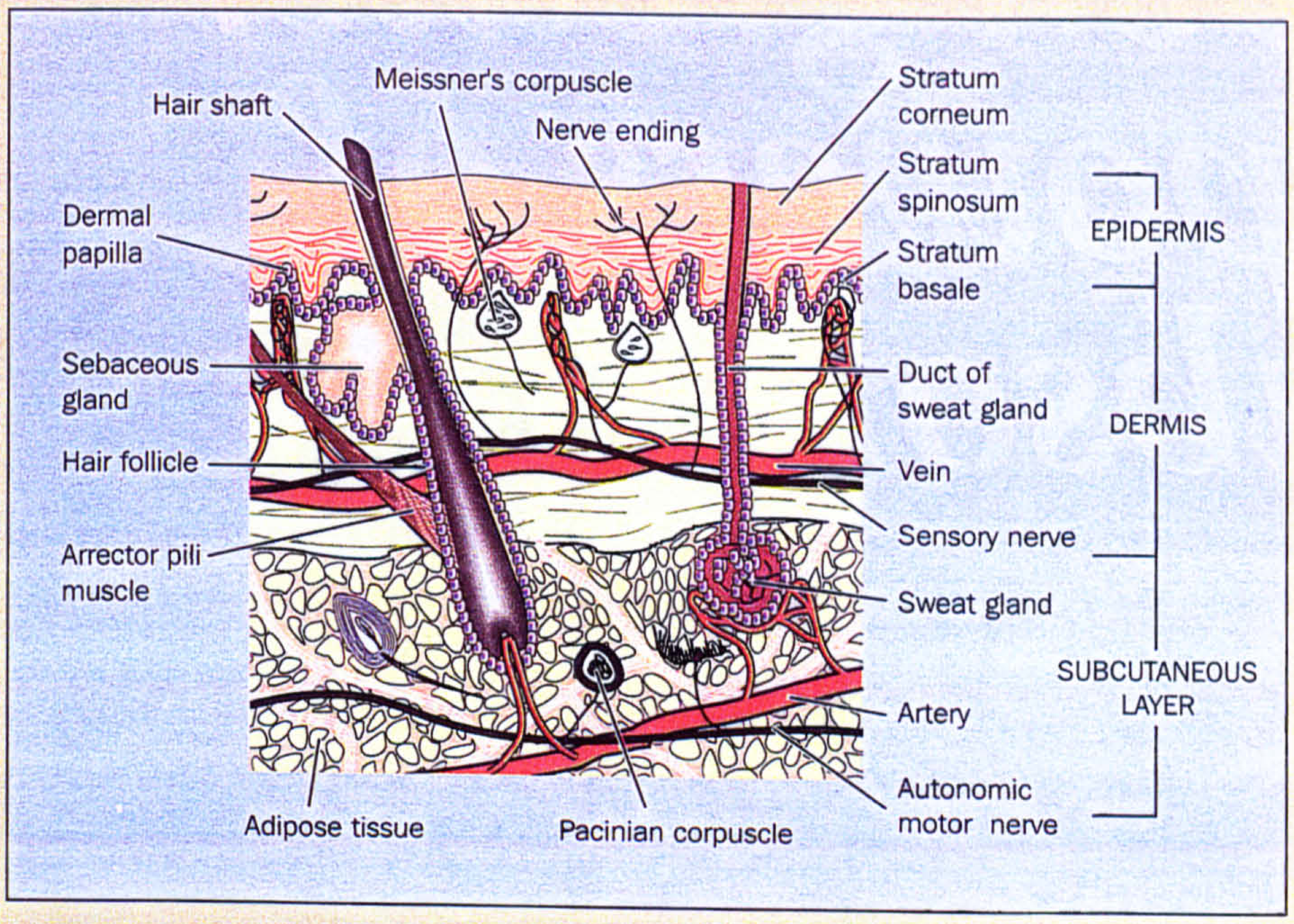

Figure 1. The structure of the skin (adapted from Tortora and Anagnostakos, 1987).

nar or cuboid cells which rest on the dermal–epidermal junction separating the dermis from the epidermis.

This layer is characterized by intense mitotic activity and is responsible, in conjunction with the initial portion of the next layer, for the constant renewal of epidermal cells. The human epidermis is renewed about every 15–30 days, depending on the region of the body, age and other factors (Junqueira et al 1977). These cells acquire their oxygen by diffusion or active transport from the capillary networks in the dermis (Collins, 1998).

2. ***Stratum spinosum:*** This layer comprises 8–10 rows of cells which provide opposition to mechanical disruption. It is made up of cuboid, polygonal or slightly flattened cells with a central nucleus and a cytoplasm that contains processes filled with bundles of fibrils. This layer is held together by small cellular extensions called desmosomes, which are linked to the spinosum and cover the whole surface of the skin. These give the cells a prickly studded appearance when viewed under a microscope.

The stratum spinosum contains nerve endings for sensation and touch. The bundles of fibrils, which are visible under the microscope, are called tonofibrils (fine filaments) and are believed to form cellular bridges that unite cell to cell. The filaments are the main precursor of keratin and spread throughout the cytoplasm, extending into the intercellular ridge to converge at the desmosome (Junqueira et al, 1977).

3. ***Stratum granulosum:*** This layer comprises three to four layers of flattened polygonal cells containing centrally located nuclei and cytoplasm. The stratum granulosum contains kerato-hyatin which gives colour and waterproofing to the epidermis (Junqueira et al, 1977).

4. ***Stratum lucidum:*** This layer is made up of several clear, flat dead cells, and is found on the palms of the hand and the soles of the feet.

The cells are translucent and composed of a thin layer of flattened eosinophilic non-nucleated cells (Junqueira et al, 1977).

5. ***Stratum corneum:*** This is the outer layer of the epidermis and consists of 25–30 layers of closely packed dead cells. Flattened dead cells containing keratin are constantly being shed. This layer is tough, waterproof and acts as a barrier to bacteria and chemicals.

These cells are constantly being worn away and replaced which takes 15–30 days (Junqueira et al, 1977; Collins, 1998).

Dermis

The dermis is a thick layer of strong connective tissue containing blood vessels, nerves, glands and hair follicles. These structures are held in position by collagen and elastin.

This layer is further divided into two strata. The upper stratum is termed the papillary region, and contains Meissner's corpuscles (the nerve endings responsible for touch). The deeper layer is called the reticular region, and comprises capillary loops and a matrix of collagen and elastin which is used in temperature regulation and excretion of excess body heat, and acts as a cushion against physical and mechanical damage (Bridel, 1993). This layer also contains Pacinian corpuscles — nerve endings that are sensitive to pressure. It is these nerve endings that direct your brain to reposition the body and so relieve pressure after sitting in one position for a long time.

AETIOLOGY OF PRESSURE SORES

It is well established that pressure sores occur as the result of a combination of extrinsic and intrinsic factors (Bliss, 1993; Bridel, 1993). Dealey (1997) divides the origins of pressure sores into three categories: intrinsic, extrinsic and external factors.

Extrinsic factors

There are three extrinsic factors that predispose to pressure sores either alone or in combination: pressure; shear; and friction.

Pressure: Pressure develops when soft tissue over a bony prominence is compressed between a hard surface and bone. If the resultant pressure is greater than capillary pressure, localized ischaemia may result (*Figure 2*). When the pressure over an ischaemic area is relieved, a red area appears over the bony prominence owing to a temporary increase in the blood supply for the removal of waste products, and supply of oxygen and nutrients. This is called 'reactive hyperaemia' (Dealey, 1994).

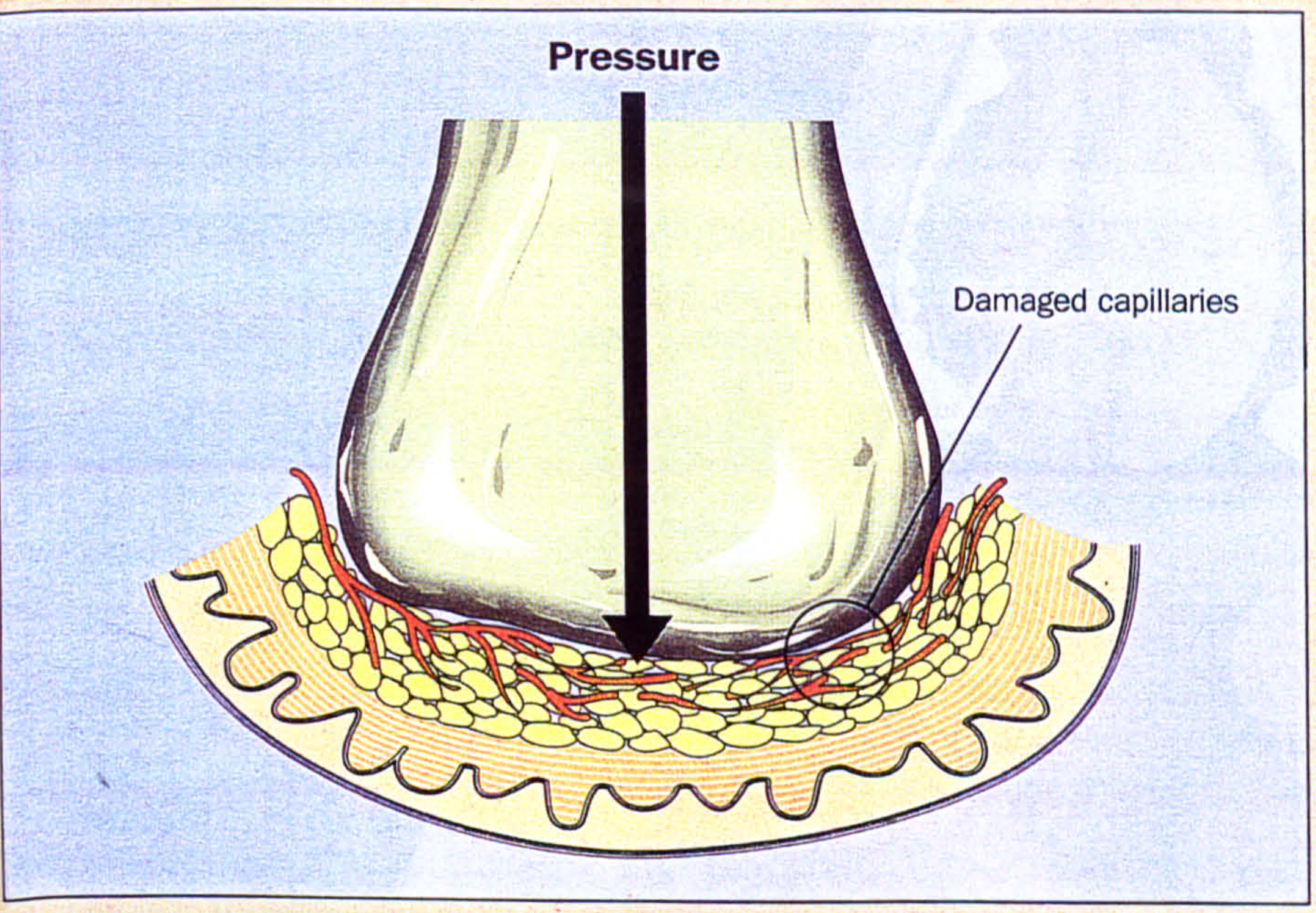

Figure 2. Skin damage caused by compression against a hard surface (adapted from Collier, 1990).

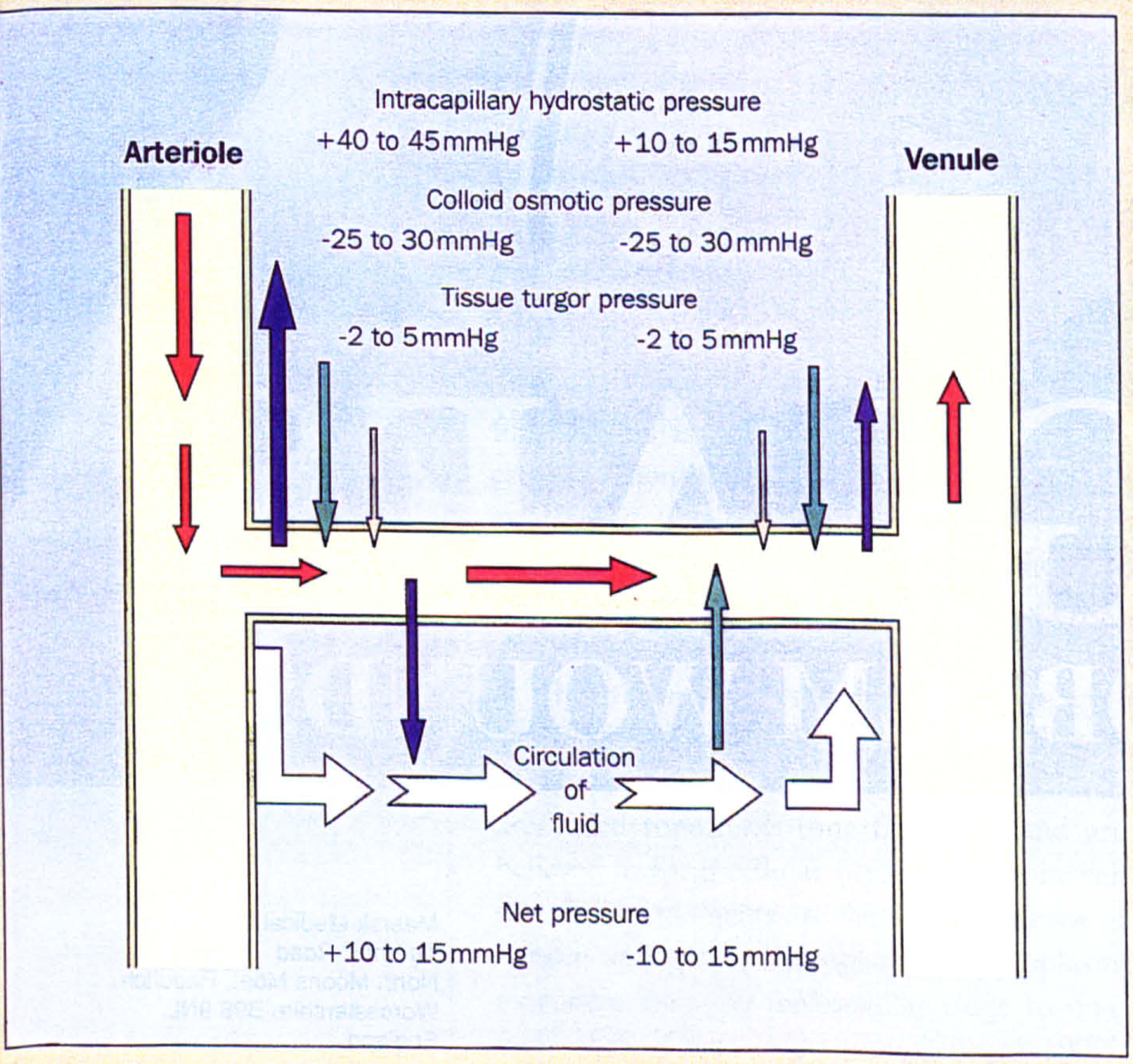

Figure 3. Starling's hypothesis of fluid distribution between blood plasma and interstitial fluid compartments (Mountcastle, 1974).

It is important to recognize non-reactive hyperaemia, when the skin does not blanch when light finger pressure is applied, as this is a precursor to pressure sore development (Bridel, 1993). Pressure sores originate in the deep subcutaneous tissues when the external pressure on the capillary exceeds the mean capillary pressure of 32 mmHg. The thresholds for elderly patients may be lower than 32 mmHg and in some individuals the capillary was demonstrated to be as low as 6 mmHg (Landis, 1931). However, literature on the precise threshold is unclear, and many issues still need to be investigated.

When the duration of capillary occlusion is excessive the blood supply ceases, the tissue dies and a pressure sore results. If the patient is in shock this process occurs rapidly owing to the reduction in blood pressure and resultant capillary occlusion.

The closing down of the microcirculation leads to oedema and the formation of microthrombi in the vessels. This causes erythrocytes, platelets and leucocytes to clump together, leading to leakage of exudate into the tissues. This in turn may cause the basal cells to separate, with progression to destruction of the dermis, sweat glands and hair follicles (Waterlow, 1988). The process governing the formation of oedema is explained by Starling's hypothesis (*Figure 3*).

Oedema occurs when the outward forces exceed the inward forces, producing an excessive accumulation of interstitial fluid. However, there has to be a large imbalance in these forces acting at the capillary walls before oedema occurs (Herbert and Alison, 1996). This explains why oedema is not always present in patients who have a pressure sore.

There are many causes of oedema and some are linked with the development of pressure sores. A patient who is malnourished may have a low plasma protein; this may cause the capillary walls to become porous and give rise to oedema. There is no clear evidence of the role that oedema plays in the formation of pressure sores and further research is needed.

Landis (1931) measured capillary blood pressure in human skin and found the average capillary closing pressure to be 32 mmHg.

The capillary bed pressure at the venule end is 12 mmHg. However, these readings are not surface pressure but intracapillary pressure. Landis also commented that 'capillary pressure is not constant, it changes from individual to individual'.

Le and Marsen (1984) investigated the pressure recordings at different levels of the skin surface and found that, while surface pressure may remain below 32 mmHg, internal pressures may be three to five times greater near a bony prominence and suffic ent to impair capillary flow (*Figure 4*). Bridel (1993), however, suggests that Landis' view of the microcirculation is inadequate, as it does not take into account the protective effects of collagen, which acts as a buffer to external pressure. Since the collagen content of the dermis alters with age and disease, the figure of 32 mmHg capillary closing pressure will vary with the individual.

Lowthian (1982), Kroupskop (1983) and Bridel (1993) discuss the importance of distinguishing when capillary occlusion is the cause of a necrotic pressure sore, as many key factors are involved in the formation of pressure sores, including pain, impaired sensation, and circulatory and lymphatic impairment but it is not always possible to distinguish when a pressure sore has occurred through pressure alone.

Kosiak (1961) confirmed that there is a connection between the level of pressure and the time for which it is exerted, and that pressure exceeding 200–500 mmHg at heart level will produce necrosis within a short period. However, it is not precisely known how long it takes for a pressure sore to develop. Kosiak concluded that:

> **'Since it is impossible to completely eliminate all pressure for a long period of time, it becomes imperative that the pressure be completely eliminated at frequent intervals in order to allow circulation to the ischaemic tissues'**
> (***Kosiak, 1961***).

Lowthian (1995a) found that 40–45 mmHg pressure may take 50–60 hours to produce pressure damage. He concluded that this is probably the maximum time that the skin can withstand simple ischaemia. However, simple ischaemia fails to explain how serious deep sores may occur after just a few hours' immobility.

Daly and Chimoskey (1976) suggest that the soft tissue becomes increasingly deformed under a sustained loading point. When sufficiently deformed, the microvasculature becomes overstretched and partially torn, producing multiple microthrombi (Lowthian, 1995b). Thus areas of necrosis, appearing particularly over bony prominences, are believed to be precursors to deep pressure sores.

Lowthian (1997) suggested that a new pressure/time curve needs to be designed for patients in bed as these measurements were designed for wheelchair users who have no sensation below the waist. He concluded that:

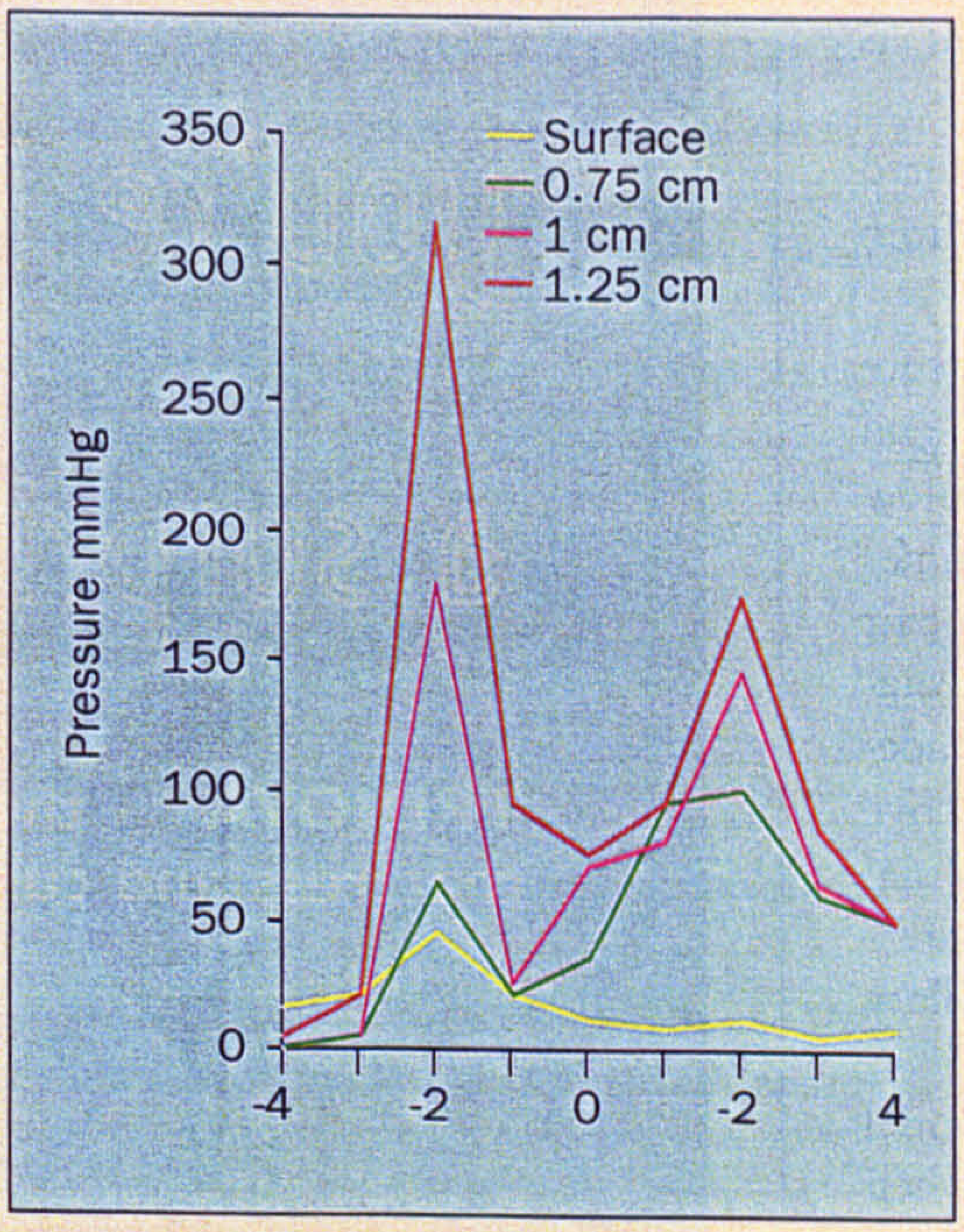

Figure 4. Approximated graph of the pressure distribution sampled at different planes in tissue underlying the left trochanter and the ischium, and measured at the surface, showing that internal pressure may be three to five times greater than the surface pressure.

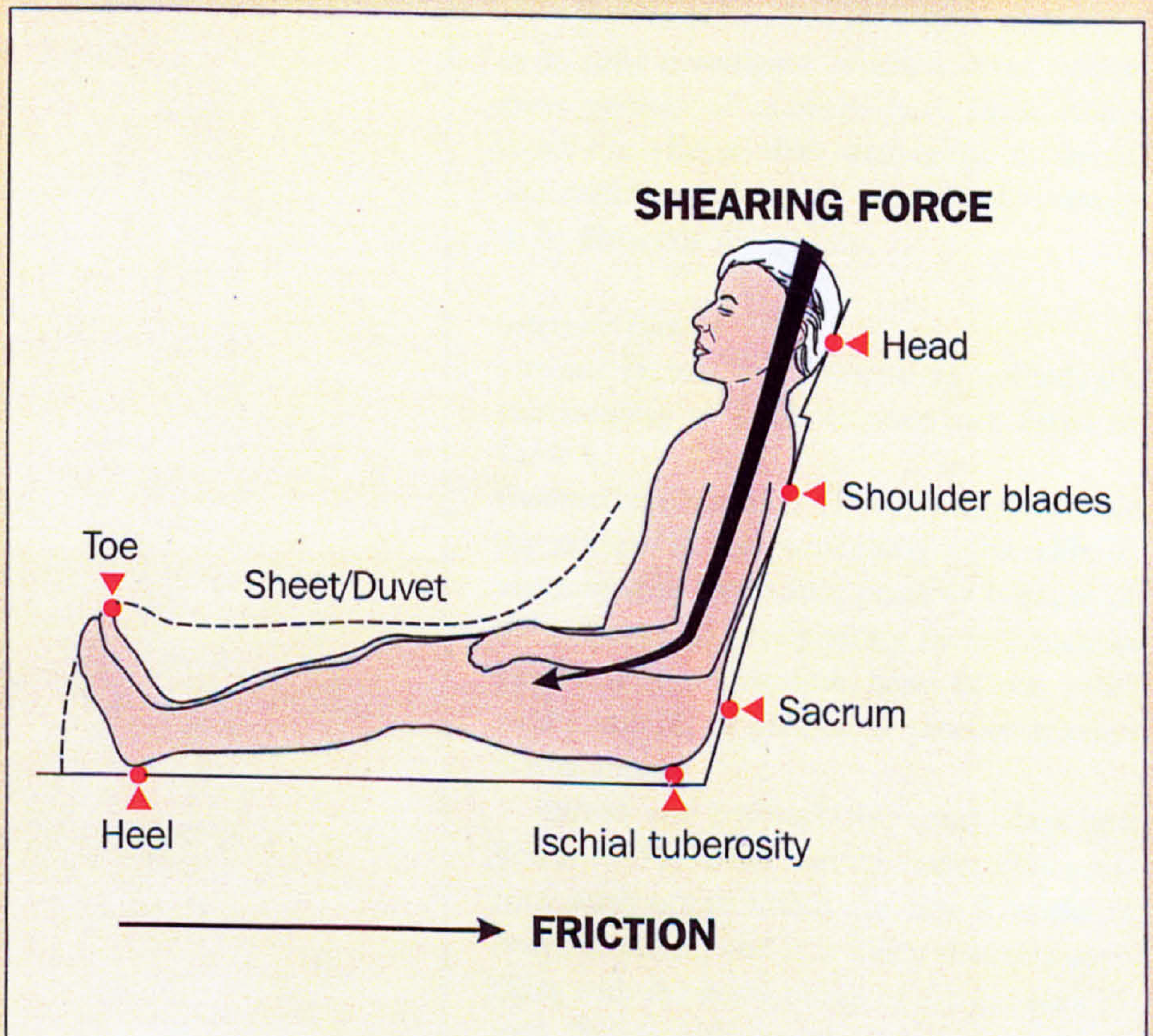

Figure 5. Patient in semi-recumbent position and the forces of friction and shear.

'If we could be more precise about the length of time that various at-risk patients can be safely maintained, i.e. in the nursing position or wheelchair, we should be able to reduce the incidence of serious pressure sores.'

Shear: Shear forces are one of the most dangerous problems facing a patient who is being nursed semirecumbent or in a chair. Shearing forces destroy the microcirculation by causing thrombosis of the vessels. Such forces occur when patients slip down the bed, or when their heels are dragged on the bed while they are being lifted up (Versluysen, 1986; Waterlow, 1988). In the case of seated patients, gravity pushes the body down, encouraging them to slump and slide down the chair.

Lowthian (1997) claims that it is practically impossible to measure, with confidence, the forces involved in pressure sore formation. It is exceptionally difficult to measure static friction and shearing of the skin.

Friction: Friction can be described as the resistance of one surface to another moving over it. Friction causes stripping of the skin, leading to superficial ulceration on areas such as the heels and elbows (Waterlow, 1988). It occurs when two surfaces rub together; as a result, the top epithelial cells are scraped off, leading to superficial ulceration on the heels and elbows (Waterlow, 1988; Dealey, 1994). Friction may occur, for example, when a patient is returned to a sitting position in bed (*Figure 5*): when the patient is slid along the sheet, rather than being lifted clear of the sheet, friction will take place at the skin surface.

Walsh and Ford (1992) comment on the strange ritual of rubbing the buttocks to improve the circulation. This was first advocated by Hughes (1989), who stated that in all cases the rubbing should be very thorough, so as to improve the circulation. It has also been suggested that standing the patient up and giving the buttocks a 'good rub' to get the circulation going actually did more harm than good (Olson et al, 1992).

Dyson (1978), Bailey (1984), Bliss (1985), and Redfern (1986) have all pointed out that excessive massage could cause tissue damage. Pritchard and Mallett (1993) maintain that massage causes skin maceration and degeneration of subcutaneous tissue, especially in

'...reduced movement and the development of pressure sores were strongly related. Confused patients on antidepressants and opioids, who may not move of their own accord to relieve their pressure areas, are therefore at increased risk of pressure sore development.'

Table 2. Intrinsic factors that increase vulnerability to pressure sores

Loss or reduction in mobility
Neurological injury
Pain
Sedation
Reduced levels of consciousness
Severe or terminal illness
Circulatory disorders
Incontinence

elderly people. Despite this, Eliopoulous (1993) advocates massaging the edge of pressure sores, Kanazawa (1990) recommended that massage should form part of preventive care, and Windmill (1992) reported that massage encouraged the circulation.

Massage of the skin is still controversial: Anthony (1996) was unable to find any evidence of a positive effect from massage, but no experimental studies have been undertaken to fully investigate its effect. Even where short periods of massage have been monitored the effects were damaging; therefore one might expect longer periods of massage to be distinctly dangerous.

Intrinsic factors

Intrinsic factors that increase an individual's vulnerability to pressure sores are listed in *Table 2*.

General health: Bliss (1990) suggested that the acutely ill are particularly vulnerable to pressure sore formation, possibly because of the presence of precipitating factors such as pain, low blood pressure, heart failure, vasomotor failure, or peripheral vasoconstriction due to shock.

Barton and Barton (1985) and Clark and Farrar (1991) found that the majority of pressure sores occur within the first 2 weeks of hospitalization, and it is likely that this coincides with the acute phase of the patient's illness. People with chronic diseases and elderly people who live alone may eat small, unbalanced meals which lack vitamins and minerals. Lack of money, weakness and depression can also contribute to the problem of a poor general state of health (Morison, 1993).

Age: A survey by David et al (1983) revealed that 85% of patients with pressure sores were over 65 years old. Thinning of the dermis, leading to decreased elasticity of the skin, could account for the increased susceptibility of elderly people to pressure sores. The collagen in the dermis provides a buffer which helps to prevent disruption of the microcirculation (Kroupskop, 1983). Also, it takes longer for a sore to heal in an older person than a younger person. As age increases, so too does the likelihood of chronic illness, which also predisposes to the development of pressure sores.

Reduced mobility: A patient's mobility may be reduced for a variety of reasons, e.g. neurological deficit such as paraplegia, multiple sclerosis, diabetes, spinal injury or degeneration, or major surgery. Reduced mobility has been identified as increasing the risk of pressure sore development (David et al, 1983; Dealey, 1997).

Decreased consciousness: Brown and Boosinger (1985) found that reduced movement and the development of pressure sores were strongly related. Confused patients on antidepressants and opioids, who may not move of their own accord to relieve their pressure areas, are therefore at increased risk of pressure sore development.

Bodyweight: Emaciated patients have no 'fatty padding', particularly over bony prominences, and so have less protection against pressure sores. Very obese patients are also at high risk as they are difficult to lift in bed and may be dragged, resulting in increased shear. Additionally, when obese patients sweat, the fluid becomes trapped in the rolls of fat, causing the skin to become macerated.

Both extremes of patient may also have poor nutritional status (Dealey, 1997).

Incontinence: Moisture increases the risk of pressure sore formation, particularly in association with friction and shear (Torrance, 1983). Contact with urine and faeces is known to lead to skin maceration and excoriation, which increases the skin's vulnerability to friction and shear (Flanagan, 1993). In addition, constant washing removes the body's natural oils by drying the skin (Jordan and Clark, 1977).

Nutrition: A balanced healthy diet is essential, not only for health but also for maintaining skin integrity. The benefits of good nutritional status are often overlooked (Liyanage-Johnson, 1995). One reason why malnutrition often goes unrecognized is that doctors and nurses are not used to looking for it (McWhirter and

‘Hard surfaces on chairs, trolleys and commodes may...cause friction on the skin. Clothing that is too tight or difficult to undo can result in trauma on removal. Patients who are wheelchair dependent should ideally wear garments that are practical as well as fashionable.’

Pennington, 1994). Also, nutrition and malnutrition are not always included in professional training curricula and so the symptoms of malnutrition may not be noticed by ward staff (Bond, 1998).

Nutritional status plays a very important role in the formation of pressure sores. It is well established that patients are often malnourished on admission to hospital. Therefore, when an elective admission is planned, patients need to be encouraged to take an adequate diet before admission (Bond, 1998). However, this is not possible before emergency admissions; anecdotal evidence suggests that often these patients are even more poorly nourished.

Patients often have a poor understanding of what constitutes a balanced diet, and need to be assessed carefully to ascertain whether they are eating an *average* diet (e.g. three balanced meals a day) or a *poor diet* (one or two inadequate meals a day).

Poor blood supply: Patients who have poor oxygen perfusion due to heart disease, peripheral vascular disease or diabetes have a lower peripheral capillary pressure. Jointly these cause tissue malnutrition (Dealey, 1997). Drugs may also cause peripheral vasoconstriction and reduce the patient's mobility.

External factors

External factors may exacerbate some of the extrinsic or intrinsic factors that contribute to pressure sores. For example, it is essential to use the correct lifting technique during repositioning of the patient to avoid friction or shear. Pressure damage can be avoided by turning the patient at least every 1–2 hours to ensure good tissue perfusion, but the optimum time interval for repositioning is unknown. Poor lifting and handling technique can result in a patient being dragged up the bed rather than lifted (Dealey, 1997).

Hard surfaces on chairs, trolleys and commodes may also cause friction on the skin. Clothing that is too tight or difficult to undo can result in trauma on removal. Patients who are wheelchair dependent should ideally wear garments that are practical as well as fashionable. It is well known that diabetic patients should not wear tight shoes, and neither should patients with loss of sensation.

Poor hygiene may also contribute to pressure sore formation. Skin that is in contact with urine or faeces for a long period of time is at increased risk of maceration and breakdown. Also, friction forces are increased in the presence of moisture (Dealey, 1997).

CONCLUSIONS

Over the next few years, the number of people at risk of pressure sores looks set to increase. There are two main reasons for this: the number of people aged 65 years and over is predicted to increase from the current figure of 16% to 20.4% by the year 2031 (Bank, 1997); and age is known to play a key role in pressure sore development, because of loss of skin elasticity, collagen and increased episodes of chronic illness with advancing age.

In addition, there are many, as yet undetermined, factors that contribute to the development of pressure sores, and further research is required. For example, it is not known exactly how long it takes for a pressure sore to develop, what role oedema plays in pressure sore formation, why it is present in some pressure sores and not others, and how to prevent friction and shear.

A sound knowledge of the physiology of the skin and how to prevent pressure sores is fundamental to patient care. The best insurance for the safety of these patients is prevention from the moment they are admitted into our care. Prompt prevention of pressure sores is not only economically sound, but also ultimately results in high quality patient care. BJN

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KEY POINTS

- If we could be more precise about the length of time that various at-risk patients can be safely maintained in the nursing position or wheelchair, we should be able to reduce the incidence of serious pressure sores.
- The exact time it takes for a pressure sore to develop is not known.
- The precise time for repositioning is unknown.
- A balanced healthy diet is essential not only for health but also for maintaining skin integrity.
- Shear forces are one of the most dangerous problems facing a patient who is being nursed semi-recumbent or in a chair.

The importance of wound documentation and classification

Linda Russell

Abstract

Good wound documentation has become increasingly important over the last 10 years. Wound assessment provides a baseline situation against which a patient's plan of care can be evaluated. A number of documents have been implemented including the 'Code of Professional Conduct for Nurses, Midwives and Health Visitors' (UKCC, 1992), the 'Post-registration Education Project' (UKCC, 1997), 'Standards of Records and Record Keeping' (UKCC, 1998), and 'Keeping the Record Straight' (NHS Executive (NHS E), 1993). These documents require nurses to maintain their professional knowledge and competence, and to recognize any deficiency in their knowledge. Having recognized any deficiency they should read the relevant literature and/or attend a study day on wound care. Nursing records are the first source of evidence investigated when a complaint is made. Wound assessment is very complex and a standardized approach to evaluation needs to be adopted. Such evaluation should encompass colour classification, wound measurement, and classification of tissue type present in the wound. There are numerous methods of measuring wounds; these range from the simple, such as manual estimation by means of a ruler or wound tracing, to the more technical procedures, e.g. computer, image analysis, and colour imaging using hue saturation and intensity. Photography, in conjunction with nursing notes, provides a very good form of wound documentation and can provide clear evidence if required for legal cases.

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The management of wounds became a nursing responsibility in the 1930s when experienced ward sisters were trained to change dressings. Gradually, this role grew and became a nursing responsibility (Dealey, 1994). Over the last 10 years the emphasis on good wound documentation has increased due to an increase in the number of wound care products available and the increased likelihood of litigation cases.

Accurate, holistic, wound assessment needs to be made by the practitioner which requires many skills. Dealey (1994) states that the ability to make an accurate assessment of the patient's wound is considered to be an important nursing skill. Holistic wound assessment provides a baseline case upon which to focus the plan of care, set relevant goals, and apply relevant wound care products to promote healing (Briggs and Banks, 1995; Williams, 1997).

Inferior wound assessment can result in inappropriate wound management and consequently lead to increased costs in nursing time, use of products, and patient suffering (Williams, 1997). In the past, nurses have not employed evidence-based nursing practice but employed anecdotal evidence. However, in recent years this has started to change and nurses now challenge old ritualistic care.

Nurses are required to document the progress of wounds and an assessment form is a useful method of documentation (Morison, 1992; Dealey, 1994). Morison (1992) states that accurate observation of wounds can be made easy by the use of a chart that highlights the factors needing consideration when wounds are being assessed. These also serve as an aid in teaching student nurses.

Accurate documentation of wound characteristics enables comparison of the wound assessment by the nurse involved in patient care (Benbow, 1995). Correct wound assessment is dependent on an understanding of the physiology of wound healing, the factors that delay the process, and the optimal conditions required at the wound surface to maximize healing (Flanagan, 1996; Kerstein, 1997). A holistic approach to wound management needs to be employed in order to monitor the rate of healing and the effectiveness of planned care at promoting healing. Wound assessment is problematic as it is very subjective and only as good as the practitioner undertaking the assessment. Therefore, if the practitioner's knowledge is deficient in the stages of wound healing, they may be unable to correctly identify the wound status (Flanagan, 1996) and the consequence may be an inappropriate dressing selection.

The UKCC's (1992) *Code of Professional Conduct*, and *Post-registration Education Project* (UKCC, 1997) pronounce that the nurse must 'take every opportunity to develop and maintain his or her professional knowledge and competence'. Nurses have a duty, therefore, to attend study days and read relevant literature where they consider their own knowledge is deficient. However, nurses may have to undertake study in their own time and often have to finance courses themselves.

Morison (1992), and Bennett and Moody (1995) state the importance of maintaining clear, concise, nursing records. Failure to do so can be seen as a negligent act and a breach of nurses' duty of care. An agreed, nationally applied system of wound assessment forms would provide a useful framework and assist in documentation. Since no pressure sore grading system has been nationally agreed this maybe some time in coming.

Only one small study on the documenting of wound management has been undertaken (Briggs and Banks, 1995). This involved 120 patients with 152 wounds being treated at a teaching hospital in Leeds. All wounds, which included pressure sores, leg ulcers and infected wounds, required healing by secondary intention, and were graded on the Association of Enterostomal Therapists' (1987) grading system. If a patient had pressure sore damage of 2–4, then the nursing care plan was reviewed for evidence related to the treatment of the pressure sore.

The first review revealed that in nursing records only 56.2% of patients had a specific care plan outlining treatment for pressure damage. In 27.4% of cases the care plan made no mention of pressure damage, or no plan of care for pressure damage had been devised, and there was no evidence of pressure sore treatment in 16.4% of cases.

Consequently, a working group was set up to develop new wound care guidelines and a documentation form was designed based on Morison (1992) and Dealey (1994). An audit was repeated with a sample of 136 patients with 152 wounds. Great improvement had occurred and 99% of patients had a designated care plan. The assessment appeared to be more thorough when the new wound assessment form was used, as it made information available at a glance. However, the follow-up audit on the new documentation demonstrated that the first assessment was completed very fully, but reassessments were completed very poorly with regard to dressing changes and renewals.

This study clearly demonstrated that nurses completed the wound assessment form but did not understand the importance of reassessment and accurate record keeping as advocated by the UKCC's (1998) *Guidelines for Records and Record Keeping* and the NHS Executive's (NHS E's) *Keeping the Record Straight* (1993). Nursing records are the first source of evidence investigated when a complaint is made. Nurses need to keep this in mind when documenting. Hammersley and Atkinson (1991) state that nursing records produce a documentary description of the patient's stay in hospital and the nursing record is considered to be a concrete display of professional competence.

The indices for wound assessment and classification encompass many characteristics, e.g. wound classification, wound size, wound edges, undermining, type of tissue present in the wound, exudate, and condition of surrounding tissue (Hampton, 1997).

The healing process is a complex mechanism and conceivably this is why no standardized approach has ever been adopted. Flanagan (1997) suggests that if a standardized approach could be adopted it would allow competent understanding for all practitioners, easy comparisons for wound evaluation, accurate documentation, and ultimately provide the patient with cost-effective wound care and reduce suffering resulting from the wound. In America, the National Pressure Ulcer Advisory Panel (1989) and the Agency for Health published guidelines for prevention and treatment of pressure sores. The Wound Healing Society published guidelines for assessment of wounds and evaluation of healing (Lazarus and Cooper, 1994). Gentzkow (1995) commented that the guidelines were deficient in clarity on how to assess wound healing during clinical investigations.

WOUND CLASSIFICATION

Several methods of classifying wounds exist (Cuzzell, 1988; Healey, 1995; Xakellis and Frantz, 1997). The literature reviewed has not revealed the existence of an international, or even a national, wound classification system. The classification of a wound depends on the practitioner's knowledge of skin physiology (Flanagan, 1997). Direct observation is the most widespread method of assessing and classifying wounds. The colour and characteristics of the wound surface are indicative of certain types of wound (Cuzzell, 1988). Buntinx and Beckers (1996) argue that this approach is oversimplified; however, in reality it is easy and quick to use and has no cost implications.

Some practitioners, such as Torrance (1983) and Shea (1975), advocate the use of a stage system to define wounds. However, Xakellis and Frantz (1997) state that the staging system

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wound progress. One reason is that good quality pictures are particularly useful in the light of increasing legal cases. Photographs also provide a detailed picture of the wound. Photography provides a permanent record and successive pictures can be compared for the purpose of detecting improvement or deterioration of the wound (Anthony, 1987).

Louis (1992) suggested that:

> 'Word description and observation of wounds does not provide a complete overall picture. However, a photograph taken correctly can say it all.'

Another advantage of using photographs for patient care is that the effects of treatment can be monitored closely and clinicians do not have to have the dressing removed unnecessarily. It is prudent to take not only a photograph of the wound but also measurements of the wound and to record progress on assessment charts. This additional material can then be included in the patient's documentation.

The distance from which a photograph is taken is very important to prevent inaccurate comparisons due to altered visual perceptions. A consistent angle also adds to the accuracy of the wound being photographed (Louis, 1992). Patients may also be motivated by improvements seen in a set of photographs from week to week. This can act as positive reinforcement and help the patient to motivate him/herself to participate in the plan of care.

A photograph of a patient's wound provides an unambiguous image for clinical reimbursement and legal purposes. This is particularly pertinent in the USA as more litigation takes place there.

A patient's photograph, taken on admission, showing damaged skin integrity is evidence that will be of use when investigating a complaint; it will also help settle any doubt in the documentation. It is therefore advisable that photographs are taken on admission if the patient's skin is compromised by any damage clearly caused before admission. Photographs can be used not only for documenting wound history within all healthcare settings but also for the education of patients, families and other healthcare professionals.

For the best results, medical photographers should be used, as they are trained to take consistent photographs, which allow comparisons between photographic images over a period of time (Melhuish, 1997). A professional photographer will consider whether the detail can be clearly seen and if the wound will be in the centre of the picture with good background and lighting. An autofocus camera is not the ideal, but it is better than no documentation at all and is relatively inexpensive to purchase.

The Polaroid camera is portable and has the facility to provide a set distance of 10 inches from which the photograph is taken, making evaluation effortless. The advantage of this method is that the photograph is instantly produced with a grid; however, reprints cannot be made easily. When taking photographs, for whatever reason, the patient's written consent must always be obtained, particularly if the photographs will be used for slides or in published material at a later date. Flanagan (1997) states that if you chose to take your own photographs, some common rules need to be followed (*Table 3*)

CONCLUSION

Nurses play a crucial role in wound management and therefore need to have a sound knowledge of wound physiology, and the skills to assess the stages of wound healing for accurate documentation. The form of documentation is not important; it can be hand written or computer generated. The use of clear terminology is most important, as is using standardized charts for colour classification and measurement of wounds. This allows easy evaluation by different practitioners. There are numerous methods of measuring wounds; however, some of these are only practical for research purposes and are impractical for everyday use in the ward area.

It appears that the most commonly employed method of measuring a wound is by way of tracing and counting the number of squares on an underlying grid to determine the area. This material can then be placed in the patient's notes. The limitations of each available wound measurement/assessment tool have to be carefully considered.

One of the best forms of documentation is a photograph as it provides a clear and meaningful record of the wound. Photographic documentation may be used in legal cases and, in conjunction with good documentation of nursing notes, can not be misinterpreted. With advancing technology more new techniques will become available in the area

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initially works well for ulcer assessment, but is inappropriate for long-term assessment of healing. 'Pressure ulcers do not heal in reverse stages' (Maklebust, 1995). For example, a stage 4 ulcer does not also progress to stage 3 and subsequently through stages 2 to 1. Pressure sores heal through a process of granulation, wound contraction, epithelialization and scar formation (Xakellis and Frantz, 1997).

Xakellis and Frantz (1997) reviewed three strategies developed by clinical experts: the Agency for Health Care Policy (Bergstrom and Bennett, 1994), the Research Wound Healing Society (Lazarus and Cooper, 1994) and the Pressure Sore Status Tool (Bates-Jenson et al, 1992). The three groups recommended certain measures (*Table 1*) which were taken from the empirical evidence supporting effectiveness. These measures represent expert opinion regarding the clinical monitoring of the important changes that occur during ulcer healing. Unfortunately, the 11 points may not fulfil all practitioners' needs. Furthermore, not all the measures will necessarily be required to assess an ulcer.

The wound classification procedure commonly employed in England is that of the pink, red, yellow, green and black system, initially launched in the mid-1970s by a company called Lederle. Lederle recommended that Varidase was indicated for use on necrotic wounds and used a colour system for identifying wounds in its promotional literature. This system was then adopted by the Wound Care Society in 1988 (Flanagan, 1992) and is still the most common method used in practice and for teaching purposes (*Table 2*). Flanagan (1997) suggests using a classification model based on the clinical appearance of the wound and the requirements for the promotion of wound healing. Research is required to discover how nurses actually classify wounds in clinical practice.

Table 1. Clinical measures recommended for monitoring ulcer healing

Wound factors	Size/area
	Stage/depth
	Location
	Shape
	Exudate
	Necrotic tissue
	Granulation
	Epithelialization
	Sinus
	Skin edges/undermining
Surrounding skin factors	Erythema/skin colour
	Induration

Adapted from Xakellis and Frantz (1997)

WOUND ASSESSMENT AND MEASUREMENTS

Regardless of which wound assessment model is employed, the case history should be carefully studied to determine how long the wound has been present, its location, the state of the surrounding skin, and whether any undermining and tracking is present. Other factors, extrinsic and intrinsic, have to be examined, as these will also delay wound healing (Hampton, 1997). The final picture is gained when size, colour and measurement of the wound have been obtained; only then can a plan of care be made.

When assessing a wound, measurements must always be taken the same way (length and width in centimetres) with a tape measure. To increase reliability of results always measure the largest and widest aspects of the wound or measure from head to toe and side to side of the wound (Cooper, 1992). For the practitioner to decide if effective wound care is being applied, measurements need to be taken to evaluate the wound's progress. Van Rijswijk and Polansky's (1994) study demonstrated that:

> **'There appears to be sufficient evidence to suggest that weeks of ineffective treatment modalities can be avoided if appropriate clinical assessments are performed at least once a week.'**

The patient needs to be examined on the same side and in the same position at each assessment to enable precise documentation (Melhuish and Plassmann, 1994; Bates-Jensen, 1995; Plassmann, 1995).

A wound area is normally measured two-dimensionally by multiplying length and width of the wound; however, it may be measured in a more complex and accurate way. Methods of measuring a wound vary from very sophisticated methods, such as photography, planimetry, or computer imaging, to less sophisticated methods such as tracing on acetate. Volume, which is three-dimensional,

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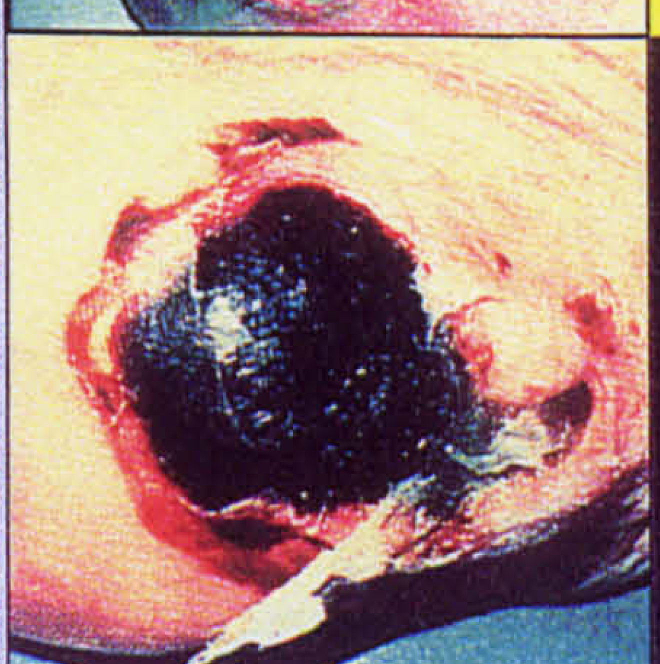
is estimated by the length, width and depth measurement or may be measured by casts or sterophotography, magnetic resonance imaging, or ultrasound. These methods tend to be employed for research projects to detect detailed changes in the wound but this procedure is both complex and costly.

Wound tracing

The most popular and cheapest method of assessment is by tracing on to transparent sheets marked with a grid which is then transferred to graph paper, or placing the traced acetate directly in the patient's notes (Plassmann, 1995). Transparencies tend to be more accessible on wards and this may be the reason why it is the method preferred by nurses. Additionally, it is the least time consuming of the methods mentioned above. This method, as it is dependent upon the observer being able to define the wound edges, is very subjective and depends on clinical judgment (Ramirez et

Table 2. Wound classifiaction

	**PINK** This is healthy tissue in the final stages of healing. Pinky white epithelial tissue migrates from the wound edges and the tissue will contain remnants of hair follicle in the dermis (Flanagan, 1997; Hampton, 1997).
	**RED** This tissue is deep red or pink and has raised uneven red granules giving the tissue a 'beefy appearance'. Fine capillary loops have been laid down and consequently this tissue can bleed easily. Hohn and Pounce (1977) state that unnecessary cleansing of granulating wounds can cause more harm and it is more beneficial to maintain the optimum environment for healing.
	**GREEN** Collier (1994) states that green exudate does not always indicate clinical infection as bacteria can colonize in wounds without harming the host. However, green exudate may demonstrate that *Pseudomonas* spp. are present in the wound bed. Pathogenic organisms can delay wound healing and the wound may demonstrate signs of clinical infection such as inflammation. Exudates from clinically infected wounds range from yellow, green, dark red/brown or grey (Hampton, 1997). Where an infection is suspected, a swab should be taken to identify the organism causing the infection.
	**YELLOW** This tissue comprises the remnants of dead cells from the wound surface. The debris contains large amounts of dead leucocytes, bacteria, and fibrous tissue, and these give the tissue a yellow creamy appearance. Flanagan (1997) states that slough is a natural part of healing, but does necessitate rehydration with a hydrogel. The presence of slough should not be taken as an indicator that the wound is not healthy, but that the wound is removing dead tissue to make way for healthy tissue.
	**BLACK** This tissue comprises hard black/brown leathery eschar. Xakellis and Chrischilles (1992) demonstrated that necrotic tissue at baseline was associated with slower healing times. This tissue has to be debrided before any wound healing can take place. The quickest method of debridement is surgical, but usually requires an anaesthetic. Conservative measures are rehydration of the tissue by scoring the tissue with a blade and allowing the hydrogel to hydrate the leathery tissue. Another method, which has gained in popularity, is biological larvae therapy (maggots) (Hampton, 1997).

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al, 1969; Majeske, 1992; Flanagan, 1997). Despite this, it is the most commonly taught method in the classroom, and it is far better to have some documentation rather than none. Measurements of wounds should be encouraged as it is an integral part of the assessment tool and must be recorded, as it is important for medicolegal reasons (Moody, 1993).

Wound tracing, however, does have its limitations in that wounds are three-dimensional and tracing gives no information regarding the depth of the wound. However, if this information is recorded separately the tracing will provide an overall evaluation of how the wound is progressing (Flanagan, 1997). Anthony (1987) suggests that wound tracing is less reliable with regard to interobserver error. It was demonstrated that the tracing method was unreliable when the longest and shortest measurements were repeated by different interobservers. The best way to overcome this problem is to have the identical observer enabling the same method to be employed. However, Anthony (1987) demonstrated that different observers obtain different readings of computer measurements of pressure sores. This was attributed to a number of reasons such as the criteria used to decide where the edge of the wound was, and different tracing techniques.

Various methods of evaluating wound tracing have been undertaken such as tracing the wound and then counting the number of grid squares covering the wound (Gowland Hopkins and Jamieson, 1983), tracing the wound areas on to acetate sheet and then cutting the shape out and weighing it (Crisculob and Oldfield, 1988). Sterophotogrammetry is used to measure rates of healing (Bulstrode and Goode, 1986) and involves the use of two cameras simultaneously. These two photographs are then analysed using a stero-comparator which produces a three-dimensional picture by combining the photographs (Anthony, 1987). All of these methods are very time consuming but have proved to be accurate.

Kundin (1985) designed a gauge which measures length and width of a wound in one single measurement. In 1989, he produced the empirical formula, shown below, that assumes a wound is irregular in shape and that only 75% of the wound's squared area can be calculated using the gauge method:

Area of the wound = length x breadth x 0.75

Thomas and Wysocki (1990) demonstrated a correlation between the gauge, acetate tracing, and photograph systems of measuring wounds. The Kundin ruler was found to underestimate the wound area by several orders of magnitude (Plassmann, 1995). The gauge systems set the standard for the measurements of wounds, despite the fact that they are the least reliable method and give a high standard deviation, making the system unacceptable for research trials.

Computers and wound measurements

Over the last 10 years the use of computers has increased considerably, particularly in wound measurement. A tracing of the wound can be transferred to a computer and the image analysed automatically (Brohannan and Pfaller, 1983; Anthony, 1987; Majeske, 1992; Ahroni et al, 1993). Palmer et al (1989) used a camera linked to a computer to measure wound area. However, it was discovered that a camera angle of 200 to the perpendicular resulted in a reduction of the measured area by approximately 10%. Thus, care must be taken to standardize photography technique.

Computer analysis is a simple and reliable way to accurately and reproducibly measure wounds. It has proved far more reliable than manual measurements, which have been shown to have as much as 25% variation on repeat estimations between observers; computer measurements have been shown to be associated with a less than 0.2% deviation on remeasurement (Mekkes and Westerhof, 1992). Current data suggest that measuring the ulcer's dimensions, exudate, and predominant tissue will provide the most valid indicators for monitoring the change in pressure ulcers over time. One of the major problems with trying to measure a wound is the natural curvature of the body; this is due to the fact that all the tools used for measurement are designed to measure wounds as a flat object; consequently, they will be inaccurate (Plassmann, 1995).

Using five volunteers, three of whom were male and two of whom were female, four of whom were right handed and one of whom was left handed, Taylor (1997) studied various shapes, i.e. circles, rectangles, and polygons, traced by a computer program — 'mouseyes'. A mouse was used to trace image outline, which was then stored on to the personal computer. The program was designed to digitize the perimeter of an image and then calculate the surface area within it, and also to calculate the linear distances between features within an image.

The results demonstrated that this system's accuracy was associated with a 1.3% error (which was less than Taylor's (1995) studies, which had a 2% error). This work highlighted problems with shapes of less than 1 cm^2. Taylor suggests that magnification would solve this problem. Several measurements had to be taken but this was not always practical with the patients enlisted for research. Angular shapes posed particular problems, as their straight sides needed to be aligned with the vertical and horizontal axes. Further work is required to improve the system so that it is more accurate and reproducible.

Melhuish and Plassmann (1994) investigated 14 patients, seven with pilonidal sinus excision and seven with abdominal wound cavities after surgical procedures. Wounds were evaluated at weekly intervals using structured light measurements for the area, volume and depth. The wound edges were highlighted with a mouse, and the computer calculated the number of pixels in the area being studied. Results demonstrated a correlation between volume and circumference using the Gilman (1990) formula to standardize the measurements. One criticism cited by Melhuish and Plassman (1994) is the problem of measuring the area and volume with any degree of exactness due to the location of the wound. As a result of the correlation between wound circumference, wound area, and wound volume, it is possible to monitor a wound's progress by measuring the circumference.

Hue saturation and intensity

Hue saturation and intensity (HSI) analysis perceives colour using a similar mechanism to the human eye. Colour is specified using measurements of three primary colours, just as the eye does using nervous impulses from colour-specific rods and cones. Hue measures the wavelength of the main colour. Saturation is the amount of white light included within the colour, and intensity is a measure of brightness. The HSI components are independent, so any change in brightness or contrast of the original image results in a change of a single HSI component. Thus, any changes between/within wounds can be seen easily and quantified.

No studies exist on using HSI for measurement and classification of pressure sores. Boardman and Melhuish (1994) studied 10 patients with pilonidal excision and abdominal wound and groin abscesses. Eight patients healed normally and two had wound infections which were confirmed with positive cultures. Various infected wounds were studied, including abdominal wounds, groin abscesses, and pilonidal excisions. Healing was measured using image analysis which demonstrated that HSI analysis provides an improved means of identifying wound areas. The authors demonstrated that subtle changes in the continuous percentage hue colour traces can indicate problems with the wound.

A recent study on a burns patient using colour imaging discovered a high correlation between wound severity and HSI at 5–7 days. It was concluded that this method could be used for tracking wound severity in a clinical setting (Hansen et al, 1997).

Wound depth

The depth of a wound can by measured in a number of ways, e.g. using sophisticated sterophotography, ultrasonic scanning and probing the wound with a swab, and examination with gloved finger (Krasner, 1992; Plassmann, 1995; Flanagan, 1997). Techniques employed in research are unsuitable for the clinical setting and everyday use (Franz and Johnson, 1992; Gentzkow, 1995). Dimensions of a deep wound should be measured using a cotton tipped applicator to enable gentle examination. The other practical method of assessment of deep wounds is a gloved finger (Cooper, 1990). Both of these techniques are subject to a degree of accuracy dependent upon where the measurement is taken, as this needs to be repeated on reassessment.

PHOTOGRAPHY

Over the last few years photography has become a popular method of recording

Table 3. Rules for photography

Patient identity should always be kept confidentiai
Close up shots of the wound need to be in focus to provide good quality photography
The background needs to be green to provide a contrast
Subsequent photographs need to be taken in the same position
Photographs need to be stored in a secure place

Adapted from Flanagan (1997)

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The distance from which a photograph is taken is very important to prevent inaccurate comparisons due to altered visual perceptions. A consistent angle also adds to the accuracy of the wound being photographed (Louis, 1992). Patients may also be motivated by improvements seen in a set of photographs from week to week. This can act as positive reinforcement and help the patient to motivate him/herself to participate in the plan of care.

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of research; however, for everyday use the available techniques need to be simple and quick so as not to interfere unduly with the nurse's increasing workload. BJN

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KEY POINTS

- In the past, nurses have not employed evidence-based nursing practice but have employed anecdotal evidence.
- The classification of a wound depends on the knowledge of the practitioner of the physiology of the skin.
- For the practitioner to decide if effective wound care is being applied, measurements need to be taken to evaluate the wound's progress.
- Photographs also provide a detailed picture of the wound.

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Understanding physiology of wound healing and how dressings help

Linda Russell

Abstract

One of the most fascinating features of the human body is its ability to repair damaged tissue. When the skin is injured a complex process occurs. The natural healing process can be divided into four distinct stages: inflammatory, granulation, epithelization and maturation. This process can take up to 2 years. Brunner and Suddarth (1992) classified wound healing into three stages: primary; secondary; and tertiary. Many factors affect how long a wound will take to heal, e.g. concurrent illnesses, nutritional status and the dressing used. A holistic approach to wound care is the key, and if all the factors are not addressed then wound healing will not prevail.

A complex set of events occurs upon injury to the skin, which appear to be relatively simple but, in fact, are exceptionally complicated giving rise to physical and chemical reactions and cellular episodes. Flanagan (1996) states that 'wound healing can be defined as the physiological process by which the body replaces and restores the function of damaged tissue'. Despite the large amount of research that has been undertaken in this field, there are still areas which are not properly understood.

WOUND HEALING

The natural healing process can be divided into four stages: infammatory, granulation, epithelization and maturation.

Inflammatory process: The inflammatory process is a 'biological emergency' response with a latent stage of about 12 hours before any obvious healing begins (Silver, 1994). However, the activity before this is very concentrated with many complex chemical events occurring. Once an injury has been sustained by the body, platelets are released from the blood vessel, which initiate haemostasis coagulation of blood leaking from damaged, inflamed, dilated blood vessels (Kerstein, 1997). At the same time a biochemical cascade occurs that liberates thrombokinase and this is converted to thrombin. The clots from fibrinogen are converted to fibrin, which covers the wound, and brings the wound edges together. Neutrophils (white blood cells) are attracted into the wound within hours of injury. A series of elaborate messages are initiated which cause blood cells to proceed to the site of the injury bringing extra oxygen supplies to the wound and phagocytes to clear tissue debris.

Also, there is release of growth factors, several cytokines which include regulatory peptides and glycopeptides (Hopkinson, 1992). On injury, damaged cells release inflammatory mediators such as prostaglandins and histamine from mast cells. Serotonin may also be released from the basophils (also known as mast cells) that results in vasodilatation from the existing blood vessels and increased cell permeability for the neutrophils and monocytes and other white blood cells (T and B lymphocytes), thus improving the blood supply to the wound.

The reason for this increased blood supply is to remove toxins and dead cells (Tortora and Anagnostakos, 1987). Wound cleansing is commenced by the macrophages by the process of phagocytosis. Throughout the healing process macrophages are circulating and produce chemical messages to initiate wound healing (Butterworth et al, 1992). Macrophages and neutrophils are essential for the transition from the inflammatory to proliferative phase of healing (Silver, 1992).

Macrophages arrive 1–2 days and digest the fibrin and provide the defence against infection. There are also growth factors that initiate formation of fibroblasts and structural protein, and collagen for angiogenesis — the next phase of wound healing (Kerstein, 1997; Morison et al, 1997). The interleukins — cytokines — are involved in inflammation and wound healing and affect local tissue by increasing tissue adhesion and attraction of T and B lymphocytes to the site of injury.

Erythema occurs as a result of the blood vessels expanding and increasing blood supply. The endothelial cells become more permeable and this fluid may leak into the surrounding area (extravasation). The combination of these processes results in oedema,

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which may last for up to 3 days after injury (Tortora and Anagnostakos, 1987; Collier, 1996). The clinical signs of inflammation were first outlined by Celsus in AD 100 'as rubor (redness), calor (heat), dolor (pain), and oedema (swelling)' (Dealey, 1994).

The literature demonstrates that the regeneration phase ranges from 3–24 days and can be divided into two sections: granulation and epithelization.

Granulation: This occurs in deep dermal wounds (Chen and Hutchinson, 1998). Macrophages signal to the dermal fibroblasts to lay fibrils of reticulin across the wound. This is later converted to collagen. The next stage is commencement of angiogenesis. New granulation tissue is very vascular due to capillary loops, which give the tissue its classic red appearance. New tissue is composed of macrophages, fibroblasts, capillary buds and loops in a matrix of fibronectin, collagen and hyaluronic acid (Dealey, 1994). Prolonged starvation of oxygen supply will reduce the mobility of the fibroblasts and delay healing (*Figure 1*). Angiogenesis is the growth of new blood vessels which are activated by tissue hypoxia from the disruption of the blood at the time of injury (Flanagan, 1997a).

As new tissue is laid down, the wound edges contract, then the growth factors interact with the mediator cells that cause the myosin bundles to approximate the wound edges. This occurs on the fifth or sixth day after injury. Flanagan (1997a) suggests that wound contraction only occurs when the wound bed consists of healthy granulation tissue: '...this explains why no reduction in the wound size occurs until the base of the wound has been shallowed out' (Flanagan, 1997b). Large deep wounds will take a considerable time to contract and demonstrate healing. Contraction could be responsible for 40–80% of wound closure (*Figure 2*) (Irvin and Challopadhyay, 1978). If the inflammatory progress is prolonged at this stage, over granulation can occur with hypertrophic scarring.

Epithelization: This is the final stage of wound healing in shallow superficial wounds above the dermis and occurs quicker in small wounds than in wounds healed by secondary intention. Following the high activity from the growth factors cocktail, macrophages and fibroblasts continue to produce new dermis rich in collagen, Hyaluronan, fibronectin, keratinocytes, hair follicles and sebaceous glands. Epithelization is achieved by squamous cells migrating across the wound surface until the deficit is resolved (*Figure 3*) (Dealey, 1994; Chen and Hutchinson, 1998). This very delicate tissue survival is dependent on a moist environment (Winter, 1962). The new epithelial tissue is pinkish-white, which gives a translucent appearance, and is seen in granulating wounds (Flanagan, 1997a).

Remodelling/Maturation: This stage can take from 24 days to 2 years to complete. Tissue which has been deposited over the wound is fragile and therefore needs to be strengthened by more robust collagen and extracellular matrix. The main components responsible for this stage are fibroblasts and macrophages. New tissue will only gain up to 80% of its strength before the biological emergency (*Figure 4*) (Chen and Hutchinson, 1998). This is the stage where the healing process switches off, vascularization to the wound decreases, fibroblasts decrease, collagen matures and the appearance of granulation tissue changes from red to white. If a scab has been present, this will detach itself leaving new tissue underneath (Collier, 1996).

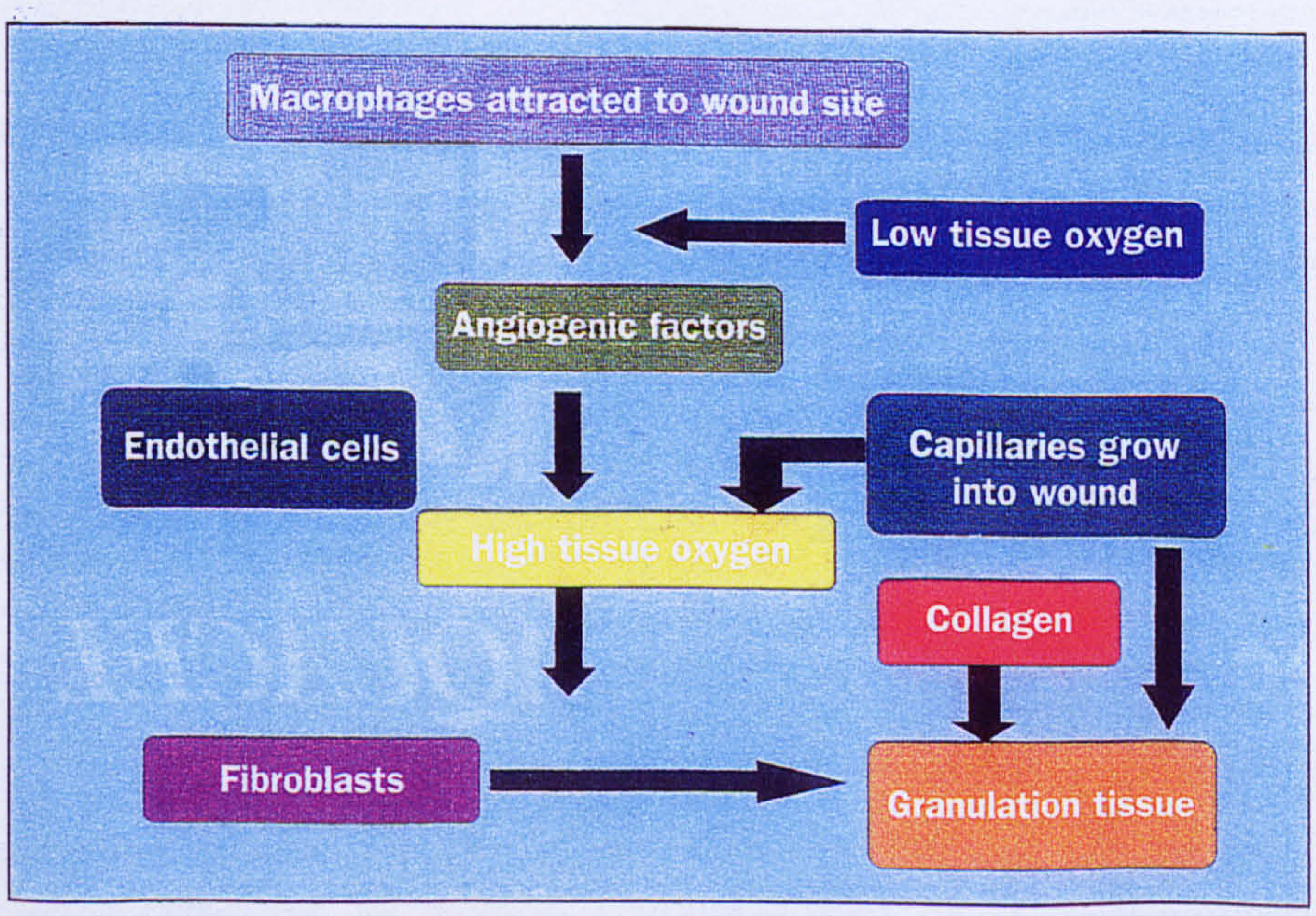


Figure 1. Healing process from injury to granulation. Adapted from Davis et al (1992).

DEFINITIONS OF HEALING INTENTION

Brunner and Suddarth (1992) classified wound healing into three stages: primary, secondary, and tertiary.

Primary intention: These wounds are usually superficial breaks in the skin through trauma or surgical procedures. Skin edges are brought together with sutures, staples or glue to enable a very fine scar to form. Primary healing is often rapid with minimal scarring (Collier, 1996).

Secondary intention: Wounds healed by secondary intention extend into the dermis or deeper layers and the defects fill slowly with new cells. These wounds may be chronic and long-standing, e.g. leg ulcers or pressure sores. They may also become infected. A holistic view needs to be taken for the management of this type of patient.

Tertiary intention: These occur when the wound has broken down following a surgical procedure. Often these wounds are infected and require surgical intervention to identify and remove the cause that may be either haematoma or large collections of pus, which may also cause wound dehiscence.

FACTORS THAT CAN DELAY WOUND HEALING

Moist wound healing

Gilge (1948) studied the effect of a moist environment on venous ulcers healed under Unna's boot and demonstrated quicker healing rates. The 'optimum environment for the natural wound healing process to be activated is warm, moist and non toxic' (Winter, 1975). Drying the wound will cause the healing process to cease. Eaglstein (1985) demonstrated that when wounds were left exposed to the air or dressed with traditional gauze dressing, which tends to lead to wound drying, the healing rate decreases by 40% when compared to a moist wound where epidermal resurfacing took place rapidly.

Field and Kerstein (1994) suggested that there are distinct advantages of moist wound healing for the patient. There is less pain because the wound is immersed in the natural body fluids and fewer infections will result, as dry eschar may harbour micro-organisms. There is also reduced trauma when dressings are changed as they will not adhere to a moist wound, with less chance of micro-organism transmission and less airborne dispersal of dried fragments of wound tissue. Autolytic debridement occurs more effectively in a moist environment and the majority of dressings require water for the hydrolysis of proteins.

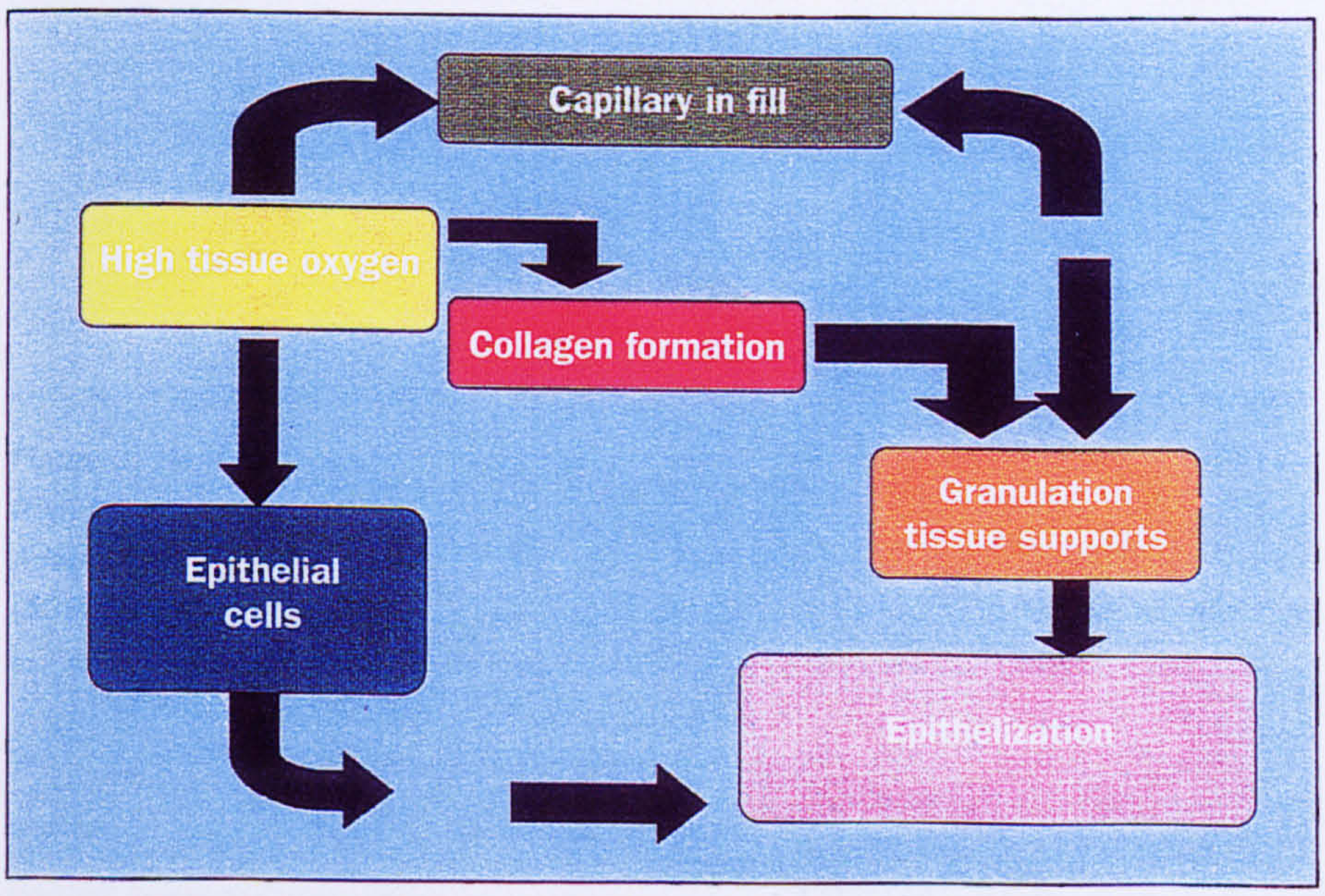
Wound exudate

Multiple components constitute wound exudate, both in terms of the nature and volume of exudate e.g. blood vessels, growth factors and wound debris, dead cells, extracellular matrix and micro-organisms (Chen and Hutchinson, 1998). Exudate also contains red blood cells and platelets that have been filtered out as the fluid passes through capillary walls into the surrounding wound (Thomas, 1997). A sudden increase in exudate may be an early indication that an infection is imminent. The production of wound exudate is dependent on many factors, e.g. whether the wound is chronic or acute. The exudate from acute wounds is abundant in growth factors which have been shown to promote wound healing (Madden and Finkelstein, 1989; Chen and Rogers, 1992; Ono and Gunji, 1994).

Very little is known on the amount of exudate produced from different wounds. Thomas (1997) and Lamke and Nilsson (1997) demonstrated that burns and leg ulcers can produce in excess of 5000 g/m^2/day. It is generally agreed that a decrease in the amount of exudate means that wound healing is occurring.

Thomas (1997) indicates that even highly experienced nurses are unable to classify

Figure 2. The process of healing for full-thickness injury through to epithelization. Adapted from Davis et al (1992).



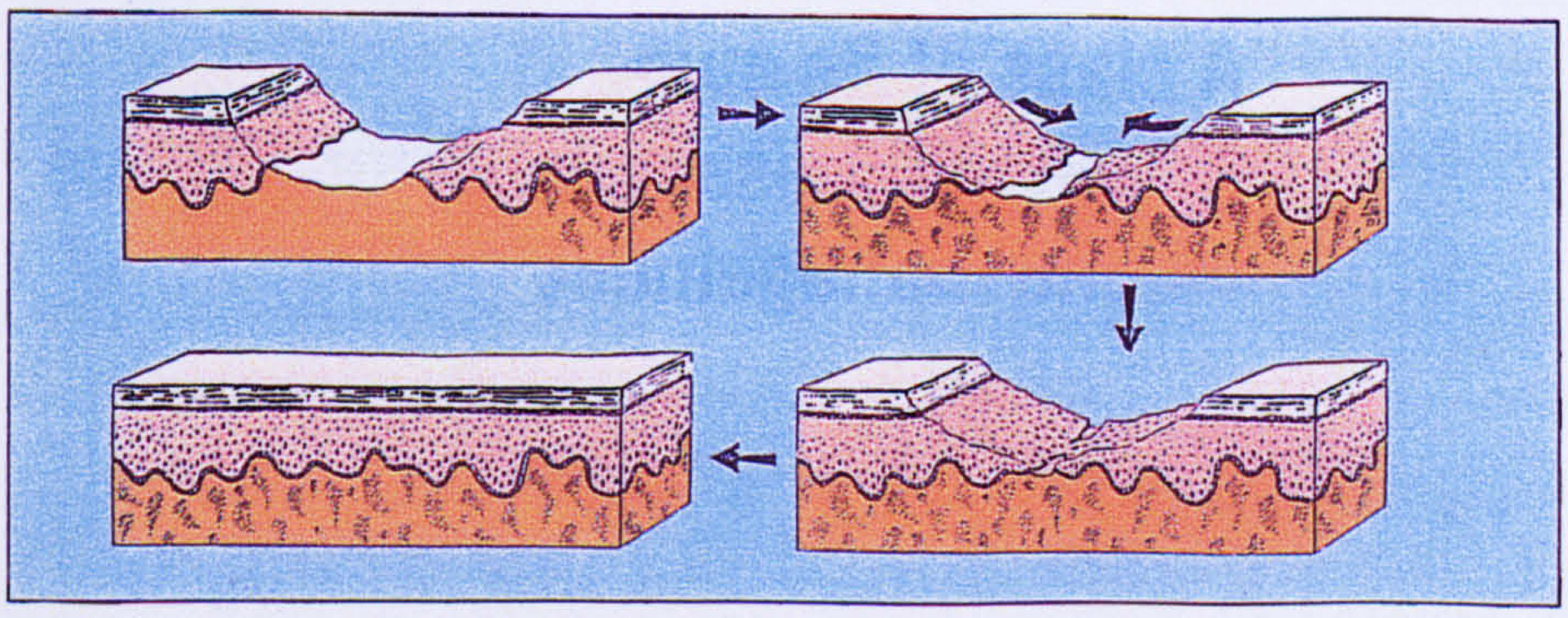


Figure 3. Migration of epithelial cells across wound surface during regeneration. Adapted from Davis et al (1992).

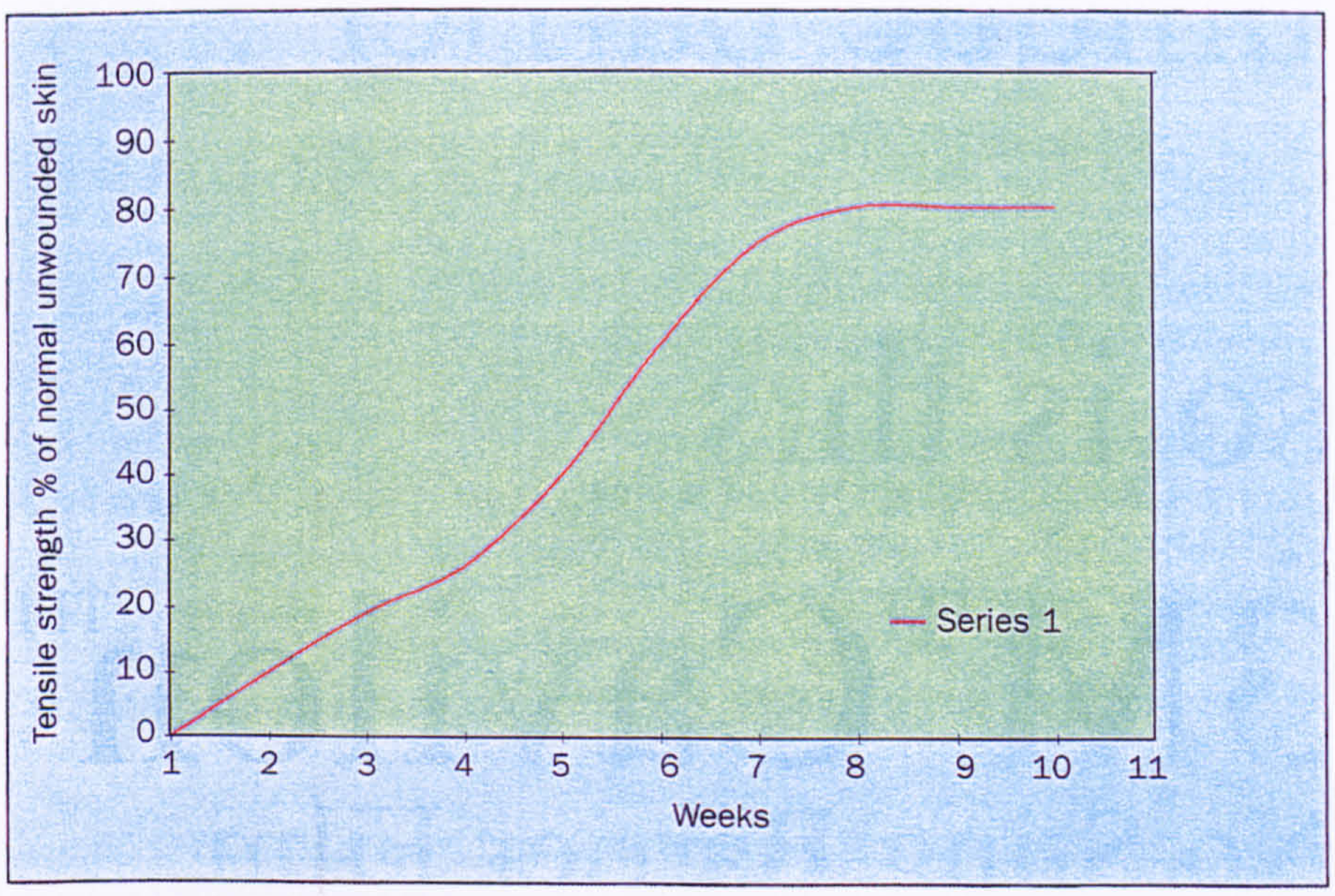


Figure 4. The tensile strength of a wound during the healing process. Adapted from Davis et al (1992).

wounds accurately according to the amount of exudate production. He studied 10 leg ulcers and measured the exudate from each patient which ranged from 0.4 to 1.2 g/cm^2/24 hours (4000–12 000 g/1m^2/day). He discovered that interpatient variation did not correlate with the subjective impressions of the investigators. Therefore, nurses should closely monitor exudate output and, where possible, document how much fluid has been lost from the wound, instead of just classifying exudate as light, moderate or heavy and assuming that everybody's perceptions are the same.

However, chronic wounds tend to contain large amounts of degrading tissue and this can actually delay wound healing (Grinnell and Zhu, 1994, 1996; Rogers et al, 1995; Wysocki, 1996). Infected wounds have a different exudate and encompass degrading tissue as well as bacterial toxins, which may indirectly delay wound healing. Excessive exudate results in skin maceration, resulting in further tissue damage around the wound which needs to be taken into account when selecting a dressing.

Age and the effects on wound healing

Ferguson (1993) stated that: 'We are ignorant of the basic scientific processes underlying wound healing, particularly in the elderly...this ignorance and resulting deficiencies in clinical management mean that the majority of wounds are maintained by nursing and medical care, not cured.'

Foetal wound healing has demonstrated that full-thickness wounds can heal without scarring and is dependent on the intrauterine development (Adzick et al, 1985). Children have a more vigorous healing rate, from the age of 1–3 years the dermis increases in thickness and from the age of 4–7 years the dermis doubles in thickness (Morison et al, 1997).

Associated with ageing are the physiological changes in the body, and these can lead to a predisposition to injury and decreased efficiency of wound healing mechanisms (Morison et al, 1997). However, our bodies age at different rates and over the age of 30 years a significant decline may occur in some systems, such as the cardiac and immune systems, which in part can contribute to longer healing times. Replacement of epidermal cells, inflammatory response, sensory perception and barrier function all decrease through the ageing process. Arterial and venous disease can delay wound healing and are a common problem in the elderly population. The effect of ageing is often compounded by concurrent illness and malnutrition. Long-standing chronic illness is known to impair appetite, as may drugs, anxiety, depression and radiotherapy (Bond, 1998).

Wounds in elderly people do, however, heal with good effect in most instances but it takes longer (Davis et al, 1992). Assessment of the patient is very important and identifying the risk factors to their vulnerability is vital with the use of risk assessment tools used for pressure sores.

Temperature of the wound

The ideal wound temperature has been identified as 37°C. A reduced temperature may inhibit the activity of cells involved with the healing process (Lock, 1980). The optimum environment is required for natural enzymes that are secreted by inflammatory cells to continue the sequence of wound healing. Modern dressings are designed to maintain this optimum temperature of 37°C. If the wound temperature falls below 28°C then leukocyte activity can stop, particularly if dressings are removed for ward rounds. Wounds should be covered with sterile cling film to maintain temperature and moisture. The reduction in wound temperature can take several hours to recover to full mitotic activity (Lock, 1980).

WOUND DRESSINGS

A huge array of dressing products are currently on the market which can be confusing to the nurse trying to decide which product to use. The demand for wound care products is growing

> In the early 1970s there were a limited number of dressings available, which were mainly traditional, e.g. gauze. One reason for the change of dressing products in the 1980s was the discovery that new blood vessels grow from zones rich in oxygen towards those with less oxygen... angiogenesis occurs more rapidly in wounds covered with hydrocolloids...The 1980s saw the introduction of hydrocolloids into routine use which encouraged moist wound healing.

Table 1. Cost comparison of gauze daily dressing to one modern application once a week

	Traditional gauze twice daily dressings	Modern dressing Aquacel and Combiderm
Cost of dressing packs	£0.60 x 2*	£0.60*
Cavity dressing	£20.50*	£7.65* Aquacel ribbon x 3
Secondary dressing	£6.00*	£6.96* Combiderm x 4
Normal saline	£1.50*	£1.50*
Tape	£1.63*	
Total	£30.83	£16.71

*These costs are average and do not include nursing time; adapted from Roberts and McLoughlin (1997)

Table 2. The benefits of moist wound healing

Outcome or benefit	Possible explanation provided
Less reported pain	Free nerve endings responsible for pain are bathed in physiological fluids
Fewer infections reported	Viable host defences, less dry dead tissue to harbour micro-organisms
Less re-injury on removal	Moist wound healing interface
Less risk of micro-organism transmission	Less airborne dispersal of micro-organisms on removal
Efficient autolytic debridement versus mechanical for traditional drying dressings	Enzymes require water for hydrolysis of proteins

Adapted from Field and Kerstein (1994)

rapidly due to demographic and technological changes (Roberts, 1998). Numerous clinical trials are now performed in order to produce clinical evidence for products. The evidence should be subjected to rigorous evaluation, including cost implications of the treatment and the healing time to the end point. Many of the current clinical trials do not address these problems.

A reason for the focus on increased efficacy of wound care products is that purchasers and the Government are concentrating on cost-effective care and measurable outcomes in treatment. Roberts (1998) suggests that cost-effective management of wounds is a complex matter and should not only concentrate on short-term healing costs, but also consider the long-term expenses. The total costs of dressings are hard to ascertain because not only do nurses apply dressings but also they may be applied by physiotherapists and chiropodists. Thus, the amount of inappropriate wound care that actually takes place is hard to detect. Professionals are now calling for clinical evidence that a product is cost-effective, and promotes quick healing. Economic evaluation should consider:

- Cost-minimization: outcome (i.e. healing) equal but price of products different
- Cost-effectiveness: clinical benefit in better efficacy drives true cost benefit
- Cost-utility: links cost in conjunction with health gain
- Cost-benefit: attempts to value all costs and consequences in same units.

The history of modern-day dressings is fascinating. In the early 1970s there were a limited number of dressings available, which were mainly traditional, e.g. gauze. One reason for the change of dressing products in the 1980s was the discovery that new blood vessels grow from zones rich in oxygen towards those with less oxygen (Knighton et al, 1983). Lydon and Hutchinson (1989) demonstrated that angiogenesis occurs more rapidly in wounds covered with hydrocolloids.

At the same time that hydrocolloids were being developed, foam dressings were also being launched. The 1980s saw the introduction of hydrocolloids into routine use which encouraged moist wound healing. Further competition between manufacturers led to the subsequent introduction of hydrogels and alginates. Technological developments have progressed to such an extent that skin replacement has now become easier. However, this is currently very expensive but cost will decrease as the demand increases.

Economics of dressings

The amount of money spent in 1999 in the UK on modern wound care products was £80 000 000 (International Monetary Fund (IMF) Data, 1999, personal communication). This can be apportioned into the hospital (£14 000 000) and community (£74 000 00). A further £15 000 000 in the community and £6 000 000 in hospitals is spent on traditional dressings (IMF Data, 1999). Dealey (1994) states that second-generation dressings are considerably more expensive than the traditional dressings they have replaced. The cost of gauze is only a few pence and products that cost £1–2 per dressing appear very expensive (*Table 1*). However, with these new dressings the wounds will not need daily changes and this may well promote quicker wound healing and save nursing time (Dealey, 1994).

PATIENT COMPLIANCE WITH DRESSING PRODUCTS

With a vast choice of products on the market, patients' acceptability of the dressing should be taken into consideration. A dressing that allows the patient to undertake normal activity will result in high compliance with treatment. In particular, the use of modern wound dressings reduces the costs of nursing time and follow-up visits. Madden and Finkelstein (1989), Newmeth and Eaglstein (1991), and Heffernan and Martin (1994) have demonstrated that hydrocolloids constantly reduced pain on removal when compared to gauze. Furthermore, hydrocolloid products can be left in place for up to 7 days (Siegal, 1996). Miller and Collier (1996) suggest that patient compliance will be enhanced when a dressing is chosen collectively with the patient.

Dressings

Having performed a holistic assessment of the wound, optimum surroundings need to be maintained to promote the natural wound healing process such as a warm, moist, non-toxic environment (Winter, 1975; Thomas, 1990). Thomas (1997) states that if these optimum conditions are met, the result is faster healing, less scar formation, fewer dressing changes, less pain and reduction in the infection rates. 'Wound healing is a continuum, and it is likely that the effect of dressings on one phase of the process influences events during the next phase' (Newmeth and Eaglstein, 1991).

Winter (1962) researched the theory that has formed the foundation of modern dressing development. He compared dry wounds and moist wounds and discovered that moist wounds granulated up to 40% faster than dry wounds. The benefits of moist healing are summarized in *Table 2*. A dressing, therefore, has to: maintain a moist, but not macerated, surface; allow gaseous exchange; prevent bacteria from entering the wound; allow removal of excess exudate; maintain the wound temperature at 37°C; ensure freedom from fibres being shed in the wound; ensure no trauma occurs on removal; and keep the wound at the ideal pH value.

A knowledgeable practitioner should have an understanding of not only the physiology of wound healing but also the dressing products they will employ to promote wound healing (Collier, 1996). In addition, Thomas

Table 3. Characteristics of dressing products

Film membranes	Permeable to water vapour and oxygen; impermeable to water and micro-organisms; provide a warm, moist environment; comfortable; convenient; permit constant observation
Foams	Provide thermal insulation; do not shed particles; maintain a moist environment; gas permeable; non-adherent; absorb significant amounts of exudate; easily removed
Hydrogels	Rehydrate wounds; debride and clean; painless to apply and remove; soothing
Hydrocolloids	Provide a warm, moist environment; impermeable to moisture vapour; impervious to liquids and bacteria; promote angiogenesis; promote granulation; protect the wound
Alginates	Provide a moist wound healing environment; absorb significant amounts of exudate; easily removed by irrigation techniques; comfortable; haemostatic properties are reported (but not in every alginate)
Low adherent	Generally used as a secondary dressing; it may, however, may be used as a primary dressing
Hydrofibre	Moist wound environment; management of a large amount of exudate; non-adherent

Adapted from Collier (1996)

(1997) states that a greater understanding is required of the properties and performance of individual wound care products, particularly in respect to fluid management characteristics.

PAIN ON DRESSING CHANGE

McCaffrey (1983) states: 'Pain is what the patient says it is and exists when he says it does.' Waugh (1990) states that social and cultural factors, personality and current psychological state influence pain perceptions. Morison (1992) suggests that a dressing chart should include a pain scale of 0–10. This would encourage the nurse to document the patient's perception of pain and the frequency. Factors which cause pain include inflammation, exposure to the air, pressure on local tissue or movement, dressing change, irritant chemicals, clinical infection and suture removal (Morison, 1992).

Pain and discomfort are often the body's warning bell, e.g. a wound infection. At this stage a wound must be inspected and assessed (Davis et al, 1992). Where possible all the factors that contribute to pain need to be taken into consideration and the appropriate analgesia given before dressing change. The characteristics of dressing products are shown in *Table 3*.

CONCLUSION

It is essential to have good knowledge of anatomy and physiology of wound healing and factors that can affect the rate of healing. A holistic patient assessment needs to be made and all factors need to be considered and pieced together. If there are deficiencies they need to be identified and corrected where possible. Understanding of the dressing employed to manage a patient's wound is also very important, particularly with the huge array of products available on the market. More research needs to be undertaken in relation to the cost and efficacy of products and healing rates. Primarily, the nurse is in a pivotal position to help promote cost-effective wound healing. BJN

KEY POINTS

- A complex set of events occurs upon injury to the skin, which appear to be relatively simple but, in fact, are exceptionally complicated giving rise to physical and chemical reactions and cellular episodes.
- The ideal wound temperature has been identified as 37°C.
- A huge array of dressing products are currently on the market which can be confusing to the nurse trying to decide which product to use.
- The amount of money spent in 1999 in the UK on modern wound care products was £88 000 000.
- The use of modern wound dressings reduces the costs of nursing time and follow-up visits.

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Web Watch

Welcome to this new regular column being introduced by the *British Journal Of Nursing*. The idea behind the 'WEB WATCH', is to bring together each week a collection of World Wide Web pages that can be found on the Internet. The content of the Web sites provided will contain information that could be useful or interesting to nurses.

In this first week of the series, WEB WATCH has searched the information super highway to bring together a collection of sites with a general wound care/tissue viability theme. As with all information found on the World Wide Web you should cross-reference any research to ensure the information is correct.

http://www.northumbriacommunity.org/tvi/ Excellent general tissue viability site from Northumbria Healthcare NHS Trust

http://www.york.ac.uk/inst/crd/ehc21.htm Informative site from York University with in-depth information on the prevention and treatment of pressure sores

http://www.nih.gov/ninr/vol3/Skin.html American government site; excellent source of references and information on pressure sores, their treatment and relevance to quality

http://www.tvs.org.uk/ Tissue Viability Society. British society with details on membership, conferences and training material

http://woundcare.org/ For the advancement of wound healing and diabetic foot pathology this search facility is particularly good

http://www.jr2.ox.ac.uk/Bandolier/band6/b6-1.html
http://www.jr2.ox.ac.uk/Bandolier/band10/b10-3.html
UK evidence-based medicine site. These two pages have some interesting information on pressure sores. But the whole site is an excellent resource for many evidence-based topics

http://www.wound.net/ A general wound care forum. You can post messages and wait for replies from like-minded colleagues (check the validity of any advice before use)

http://www.leahcim.demon.co.uk/etrs.htm The European Tissue Repair Society (a non-profit organization)

Easy connection to all of these sites and more can be found at **http://www.masltd.co.uk**

The WEB WATCH welcomes any details of sites that contain nursing/medical information for possible inclusion in the future. Please e-mail all site links to:
remora@btinternetcom

Compiled by:
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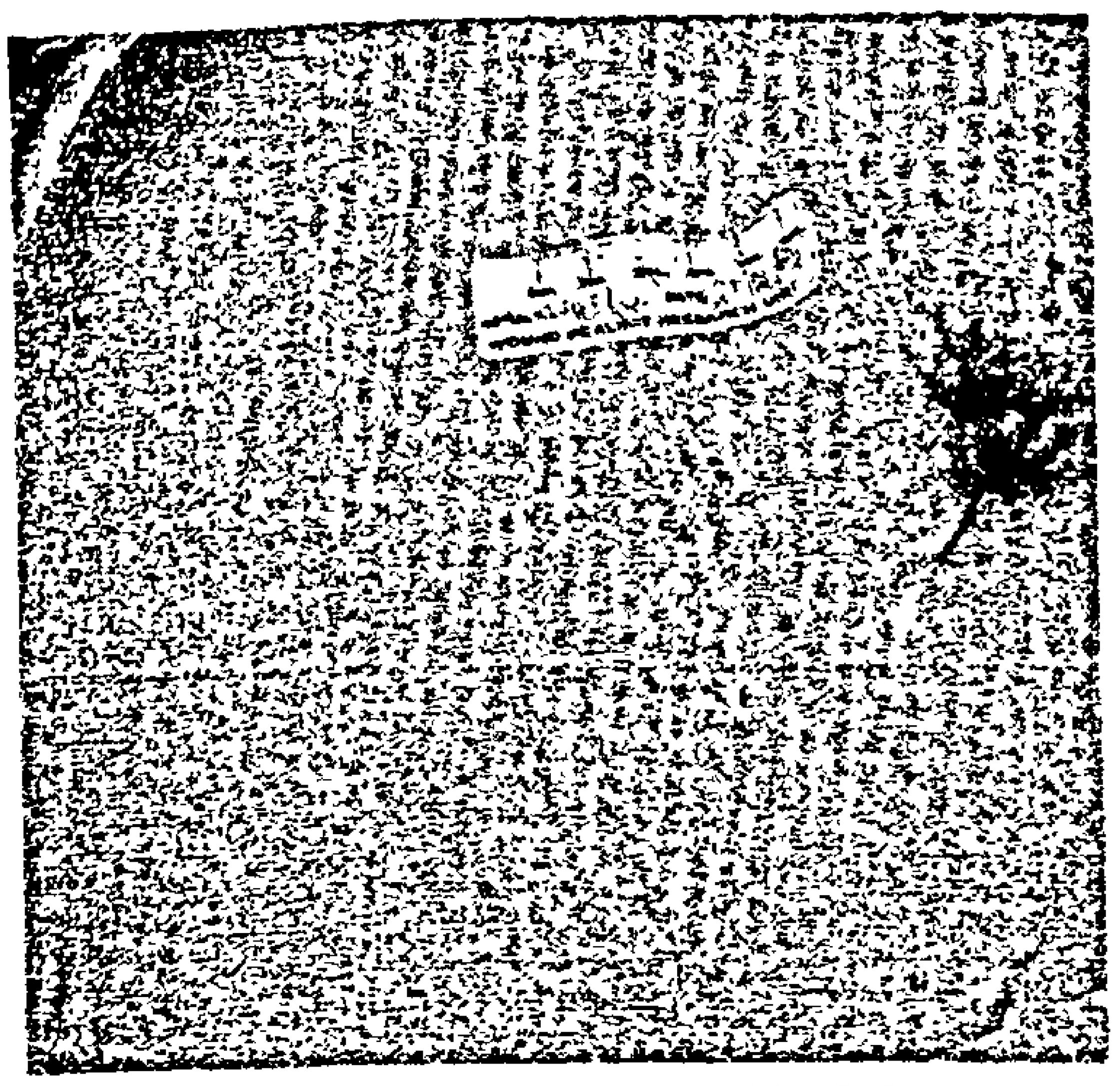
IN ASSOCIATION WITH:



Ridge marks, which are caused by lying on a matted fleece, create high capillary pressure

Bootees are often used to protect the heels, but there is no evidence to support this

WOUND HEALING RESEARCH UNIT/UNIVERSITY OF WALES COLLEGE OF MEDICINE

The sheepskin myth

LINDA RUSSELL explains why fleeces should be used only as a comfort aid, and never for pressure prevention

Artificial sheepskins were once routinely used for pressure ulcer prevention because they were inexpensive and readily available. But this ritualistic practice was not based on evidence and the limitations of their use were never considered.

There are still no guidelines on the use of sheepskins as a comfort aid within a pressure ulcer prevention framework. There is also no evidence to show that they reduce the incidence of pressure ulcers as a result of direct pressure relief (Dealey, 1991).

Some nurses still use sheepskins without realising that they provide no pressure reduction, only comfort, and that their use could actually result in a pressure ulcer.

History of use

Most hospital patients are over the age of 75 and therefore at risk of developing pressure ulcers as a result of various intrinsic and extrinsic factors.

When sheepskins were first introduced they were recommended, in conjunction with two-hourly turns, for immobile patients with fragile skins.

Fleeces were originally used for pressure relief, but they were expensive and difficult to maintain. Artificial sheepskins were then introduced because they cost less and were easier to maintain (Dealey, 1991). They were soon readily available from most hospitals' laundries and were easy to obtain in the community.

Implication for practice

It is important that nurses realise fleeces should not be used as a substitute for two-hourly turns or a mechanical bed, which would be negligent in view of the evidence provided by the Medical Devices Agency (MDA, 1994).

Its report states that sheepskins should not be regarded as a pressure-relieving device but as a comfort aid because they provide inadequate protection on sacrum and hips and are of limited use on heels and elbows.

As comfort aids, sheepskins have some advantages. They reduce friction and absorb moisture and perspiration, helping to prevent skin maceration (Dealey, 1990), and promote comfort as they conform to the patient's shape (Denne, 1979).

But even when they are used as comfort aids, nurses should be aware that there are a number of potential disadvantages. Laundering artificial sheepskins results in a matted, lumpy surface that does not provide any pressure relief (Anthony, 1996).

If matted fleeces are placed under patients they can form ridges, which create high capillary pressure (Denne, 1979). Such ridge marks may be visible on the patient's skin, particularly on the buttocks and bony hips.

Increasing the mean capillary pressure to above 32mmHg causes capillary occlusion, initiating tissue death and the development of a pressure ulcer (Russell, 1998).

KEY WORDS
- Pressure ulcers
- Pressure relief
- Sheepskins

A further risk is that sheepskins can act as a reservoir for infection (Jackson, 1983).

Taking this evidence into account, it is clear that sheepskins should be used only as a comfort aid. Natural fleeces are recommended in preference to artificial sheepskins and any fleece that is clumped or matted must be discarded to guard against ridge formation. Fleeces should always be laid flat.

Conclusion

The nurse's contribution to the prevention of pressure ulcers is paramount (Cormack, 1985) and the key to prevention is in ensuring that a full and correct assessment of the patient's risk status is made and that adequate and appropriate pressure relief is then provided.

Patients who are unable to move themselves in bed or in a chair should not be placed on sheepskins (Dealey, 1991). They should be provided with a patient support system which ensures that they receive regular pressure relief. The only time a sheepskin should be selected for a patient is as a comfort aid.

Nurses are accountable for their actions and any omission of care through lack of knowledge that endangers the patient may be seen as negligence.

Nurses should strive to practise evidence-based nursing and should not follow ritualistic practices. If they know sheepskins can contribute to pressure ulcers but continue to use them for pressure relief, a court of law could find them guilty of negligence. **NT**

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Malnutrition and pressure ulcers: nutritional assessment tools

Linda Russell

Abstract

Good nutrition is essential throughout life and often patients have a poor understanding of what a balanced diet comprises. Nurses need to have a good comprehension of malnutrition. Where malnutrition is evident it can be resolved by working with the patient to encourage a healthy diet. One way to improve patient nutrition is by a nutrition audit of patient food. Numerous nutritional assessment tools exist which help to identify a patient's nutritional status. No nationally standardized nutritional assessment tool exists and there is a danger of assessment methods becoming as proliferate as pressure ulcer risk assessment tools. A solution to this problem may be to use a pressure ulcer risk assessment tool with a nutritional risk assessment tool such as the Burton Score. Pressure ulcers and malnutrition have been demonstrated to be strongly correlated with each other. Malnutrition is not just present in hospitals but also in nursing homes. A solution to this problem is to use nutritional tools to highlight nutritional deficiency in a patient's diet not only in hospitals but also in the community and in nursing homes.

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A balanced healthy diet is not only essential for health but also is required to maintain the integrity of the body and skin. All members of the multidisciplinary team need to be aware of the importance of a well balanced diet. Observation of how much food patients eat is important where they are in hospital, at home, or in a nursing home. Are there problems that are stopping the patient from eating well such as loose-fitting dentures or not feeling hungry at the time of day that meals are served. Problems caused by malnutrition result from a prolonged period of poor dietary intake. Malnutrition needs to be recognized and acted upon as soon as possible by the practitioner.

NUTRITION

The benefits of good nutrition status are often overlooked (Liyanage-Johnson, 1995). One reason why malnutrition often goes unrecognized is that doctors and nurses are not used to looking for it (McWhirter and Pennington, 1994). A study of nutrition and malnutrition are not always included in professional training curricula, hence the symptoms of malnutrition often go unrecognized by ward staff (Bond, 1998).

Despite advances in health care, successfully preventing malnutrition remains a very large problem. The British Association for Parenteral and Enteral Nutrition (BAPEN) reported that 'despite the proven efficacy of nutritional support in both clinical and financial terms, the nutritional care of patients throughout the UK is fragmentary' (BAPEN, 1994). Currently, no national guidelines exist regarding how patients who are ill should be fed. BAPEN (1994) suggests methods of increasing a patient's dietary intake that include the use of oral supplements, and enteral and parenteral feeding.

A well balanced diet should contain carbohydrates, fats, protein, minerals, vitamins and water. The protein requirements for normal health are in the range of 0.5–0.8 g/kg daily (Pinchcofsky-Devin, 1994). The estimated average daily energy requirements for men and women aged 75 years or over are 2100 kcal (8.77 MJ/day) and 1810 kcal (7.61 MJ/day) respectively (Department of Health DoH), 1991).

MALNUTRITION

Lennard-Jones (1992) stated that the extent of malnutrition in the UK is phenomenal; nutritional support can reduce the length of hospital stay by 5–16 days. If only 10% of hospital inpatients had their stay reduced by 5 days, as a result of nutritional support, an estimated £266 million could be saved annually (Lennard-Jones, 1992). However, this surely would only be a short-term solution to the problem of patients being malnourished and serves only to pass the problem back to the community.

Malnourished patients need long-term nutritional support as they have been eating an inadequate diet over a period of years; this

> **The reasons for an increased risk of developing pressure sores in circumstances of malnutrition include loss of protein from the dermis and a decreased ability to reproduce new cells. Additionally, the natural process of ageing causes the epidermis to become thinner, so any minor abrasion will easily break down and may take an extensive period of time to heal.**

takes a long time to rectify. Education on good nutrition and improvement of quality of life needs to be initiated at a very young age, and not left until an individual becomes critically ill.

Malnutrition can be defined as:

- Inadequate food intake
- Excessive intake of unbalanced nutrition
- Insufficient specific nutrients
- Imbalance due to disproportionate intake (Lennard-Jones, 1992).

Many elderly patients are admitted to hospital in poor health, which has been evident over a number of years, and have also not been eating correctly for some years. Long standing chronic illness is known to impair appetite, as may drugs, anxiety or depression, and radiotherapy (Bond, 1998). Malnourished patients have often lost the will to live, and lack motivation (Dickerson, 1986). Many of the investigations that patients undergo as an inpatient require fasting. This means that meals are missed and that prior malnutrition is exacerbated. Patients undergoing surgery are required to fast, often only to find that operations are cancelled; this may result in a patient being required to undergo a series of fasts.

Malnutrition results in an increased risk of infection, has serious physical consequences, and may result in death either in hospital or at home (Taylor and Goodinson-McLaren, 1992). Undernutrition in hospital is a significant concern and can result in considerable morbidity and mortality (Silberman, 1989). Dickerson (1995) suggests that nurses need to be aware of malnutrition and understand its implications (*Table 1*).

The reasons for an increased risk of developing pressure sores in circumstances of malnutrition include loss of protein from the dermis and a decreased ability to reproduce new cells. Additionally, the natural process of ageing causes the epidermis to become thinner, so any minor abrasion will easily break down and may take an extensive period of time to heal.

Table 1. Implications of poor nutritional intake

Poor wound healing and increased wound dehiscence
Acceleration of the development of pressure sores
More susceptibility to infections
Muscular atrophy
Increased level of toxicity of drugs

Lennard-Jones (1992) and BAPEN (1994) both highlighted that malnutrition in hospital still remains a big problem. Assessment of patients' nutritional status on admission to hospital should be mandatory in all hospitals. A method of identifying patients who are nutritionally deficient and the provision of education for the multidisciplinary team and the patient on nutrition by a dietician are issues that need to be addressed (Morton, 1995). BAPEN (1994) suggested that nutritional support groups should be organized to provide a multidisciplinary approach to nutritional care of patients.

Plews (unpublished report for Queen's Hospital Staffordshire, 1995) undertook a longitudinal study from January 1992 to June 1995. A small random sample of 36 elderly patients on the 'elderly unit' were evaluated on six occasions to ascertain their nutritional intake. As a result of the audit, changes were made from a cooked breakfast, lunchtime meal, and light evening meal to a continental breakfast, cooked lunch, and sandwiches for the evening. The majority of the nursing staff found that this arrangement was totally acceptable. However, concerns were expressed by nursing staff on elderly care wards as they did not consider the change to be suitable for their patients; it was therefore decided to assess patient nutritional intake after the changes had been implemented.

The first audit which provided the baseline was conducted in January 1991 and demonstrated that none of the patients met daily recommended fluid requirements and that with the exception of vitamin C intake, all other nutrient intakes were lower than recommended levels. A further five audits (November 1991; November 1992; March 1993; November 1993; June 1995) were carried out and when the results were compared women's nutrient status had increased significantly with the exception of vitamin C which had decreased; however, vitamin C intake was still in excess of the recommended level in all of the audits. The men's nutrient status had decreased, but in all cases the patients with the lowest intakes, i.e. those at the bottom of the range, were greatly improved. The changes that occurred are highlighted in *Table 2*.

These changes resulted in improved nutritional intake by the elderly care patients. Regular monitoring is carried out two to three times per year to ensure that the measures remain effective. This work has demonstrated that it is possible to cater for patients' nutritional requirements and that regular audit will monitor, maintain and improve standards.

PRESSURE SORES AND MALNUTRITION

Malnutrition is a very important factor in the development of pressure sores (Ek et al, 1991; Bale and Jones, 1997). A number of studies have highlighted that 20–50% of elderly patients are admitted in a state of malnutrition (Bistrian et al, 1976; Larsson et al, 1990; Volkert et al, 1992). Cederholm (1994) demonstrated that the incidence of mortality at 9 months doubled in malnourished patients with non-malignant conditions admitted as emergency cases (44%) compared with non-malnourished patients.

Table 2. Changes occurring in relation to nutrition in one hospital following audits

Geoffrey Hodges Wing has its own regular and 'soft' menu, more suited to the preferences of elderly people. The menus are in English e.g. 'savoury mince and beans' instead of 'chilli con carne'
There is a menu board on the ward, so patients choose their menu moments before rather than 24 hours in advance
Food is provided from bulk trolleys and is served to meet the individual requirements. The patient can actually see the food before choosing. Small portions and second helpings are available as necessary
Patients, who are away from the ward at meal times, e.g. at X-ray, can obtain a hot meal on their return
A cooked breakfast is available and this has proved popular
Full cream milk is used for drinks and cooked dishes
Nursing staff have a degree of control over the times at which meals are served, so patients are no longer faced with meals too far apart
Hot drinks are served in attractive ceramic cups with large handles — these are popular with patients and are easier to hold for patients with arthritic hands
Catering and nursing staff work together at meal times and share the responsibility for patients' nutritional status
Increased awareness by staff that nutrition is a very important component in recovery from illness
Source: Plews (unpublished report for Queen's Hospital Staffordshire, 1995)

Elmstahl (1987) and Larrson et al (1990) demonstrated that hospitalization contributed to the deterioration of some elderly patients' nutritional status. Prolonged protein/energy malnutrition and deterioration in immunity and weight loss is connected with increased morbidity and mortality (Chandra and Joshi, 1982).

Elmstahl and Persson (1997) studied 67 elderly long-stay patients with diagnoses of dementia, cancer, cerebrovascular accident, and cardiovascular and other disorders. Their body mass index (BMI) was recorded. All patients were given a daily energy intake of 2000 kcal. This dietary intake was assessed using a 9-day dietary sheet and any supplements used were recorded. Two researchers, who were nutritionists, were responsible for the assessments of these patients.

The results demonstrated that 80% of men and women had low energy intake and more than half of them had intakes of vitamins D and C, iron and cobalamin below recommended levels. Interestingly, 18% of the patients with lower energy intake at baseline died within 6 months. The main finding was that long-stay elderly patients whose nutrient intake was below present recommendations had 'a higher mortality rate than among those with lower energy intake, independent of diagnosis'. The difference between nutrient and energy intake is significant, e.g. a 2000 kcal diet composed entirely of glucose would obviously be less beneficial than a balanced 2000 kcal diet comprising protein, fat, carbohydrates, minerals and vitamins. Correct nutritional assessment is required, particularly in long-stay elderly units.

The literature reveals that the majority of studies on nutrition are cross-sectional but that the strongest data are produced from prospective studies. Prospective studies recruit patients who are initially free of pressure sores and investigate the association between protein energy, malnutrition, and risk of pressure sores.

Allman and Laprade (1986) carried out a cross-sectional study of 634 hospitalized patients to determine the prevalence of sores and associated factors. There were 30 patients with pressure sores. In patients with pressure ulcers, serum albumin concentrations and weight were found to be statistically significantly lower than for patients without pressure sores. This pressure ulcer study included

> **Malnutrition has not only been detected in hospitals but also in nursing homes...patients in nursing homes have low protein levels, weigh less than their ideal body weights and have low serum albumin levels... good nursing homes that ensure patients eat well and do not progressively slip into nutritional deficiency will have a lower incidence of pressure sores.**

a prospective arm in which a smaller number of patients ($n=78$) were assessed over a period of 3 weeks; it demonstrated that 6 patients who developed sores appeared to have lower serum albumin levels than patients who did not develop pressure ulcers; however, the difference was not statistically significant.

Ek et al (1991) carried out a cross-sectional study of 495 newly admitted patients to a long-stay elderly unit; patients were assessed for their nutritional risk factors and the development of pressure sores. In the patients who developed significantly low serum albumin levels and pressure sores, low body weight was also reported. The study included a prospective arm with 51 patients who had developed pressures sores during hospitalization. A correlation was found and statistically proven between insufficient intake of food and low serum albumin levels in the development of pressure sores.

Berlowitz and Wilking (1989) reviewed the medical notes of 301 patients admitted to a chronic care hospital. A total of 100 patients had pressure sores and low haemoglobin, total protein, and serum albumin levels, and were more nutritionally impaired than their counterparts. In a prospective arm of the study in which 185 patients were observed over a period of 3 weeks it was seen that 20 patients developed pressure sores. The significant factor was the impaired nutritional intake of the patients developing pressure sores.

In a review of the literature, Breslow and Bergstrom (1994) suggest that cross-sectional studies demonstrate a correlation between having a pressure sore and inadequate energy and protein intake, being under weight, low triceps skin fold, low serum albumin, serum cholesterol, and haemoglobin levels. Prospective studies investigating the development of sores have demonstrated similar findings, i.e. inadequate energy and protein intake, low serum albumin levels, and poor Braden score (Braden and Bergstrom, 1987), which includes some aspects of nutrition.

In a small study by Holmes et al (1987), a correlation between pressure sore risk (using the Waterlow score) related to age and weight was investigated. Of patients with serum albumin levels above 35 g/litre, only 16.6% developed pressure sores; however, 75% of patients whose serum albumin levels were below 3.5 g/litre developed pressure sores. As depressed albumin can indicate a catabolic state and/or protein/calorie malnutrition, these patients require urgent nutritional support in order to reduce the risk of pressure sores developing (Holmes et al, 1987).

It appears that there is no precise answer regarding whether low serum albumin levels play a significant role in the development of pressure sores. Low serum albumin levels can be used as a surrogate marker for a patient's nutritional status. Lewis (1996) suggests that the majority of studies state that low serum albumin levels should be referred to as a predictor of nutritional status. However, the half-life of serum albumin is 21 days. A malnourished patient will take a considerably longer period of time to correct any underlying pathology before protein and serum albumin concentrations rise to an acceptable level. Albumin is thus a slow indicator of nutritional problems.

Anthony et al (2000) carried out a prospective study of 773 patients aged over 64 years and undergoing a hospital stay of at least 1 week. Using the Hospital Information Support System to export the data, all the patient Waterlow scores, serum albumin levels, and sodium levels were extracted and analysed using a SPSS (Statistical Package for Social Sciences) software package for logistic regression, and discriminate analysis. A receiver operating characteristic curve was used for sensitivity and specificity of the Waterlow scores at various thresholds.

It was statistically demonstrated that high Waterlow scores and low serum albumin levels were strongly correlated ($P=0.001$) for patients who developed pressure sores. This study recommends that serum albumin be assessed to give better predictive power to the Waterlow score; its assessment also provides greater sensitivity in identifying patients who will develop a pressure sore.

NURSING HOMES AND MALNUTRITION

Malnutrition has not only been detected in hospitals but also in nursing homes. Pinchcofsky-Devin and Kaminski (1986), Weiler and Franzi (1990), Breslow (1991), and Bergstrom and Braden (1992) demonstrated that patients in nursing homes have low protein levels, weigh less than their ideal body weights and have low serum albumin levels. Additionally, Weiler and

Franzi (1990) demonstrated that 'patients with pressure ulcers were significantly more likely to consume less than 75% of their meals than patients without pressure ulcers'.

It can be inferred that good nursing homes that ensure patients eat well and do not progressively slip into nutritional deficiency will have a lower incidence of pressure sores. Nursing home datasets do not include this information and so it is difficult to prove whether some nursing homes are better than others.

NUTRITIONAL ASSESSMENT TOOLS

A number of nutritional assessment tools, such as the Nutrition Risk Index (Wolinsky et al, 1990), are used by dieticians and nurses (BAPEN, 1994). Nationally agreed tools do not exist and there is danger that these tools will proliferate to become as numerous as the pressure risk assessment tools. However, it is better to use a tool to identify a patient's nutritional status that none at all.

Lewis (1998) studied 37 patients over the age of 75 years and recorded the Waterlow score and any presence of pressure sores. The grading scale is not clearly stated, with reference only being made to the fact that non-blanching erythema was included as a grade 0 pressure sore. Patients with fractured neck of femur were monitored from admission and underwent total hip replacement. The dieti-

Figure 1. Waterlow Pressure Sore Assessment Score and Burton Nutrition Assessment Score.

Waterlow: specific information		
Continence		
Complete / Catheterized		0
Occasionally incontinent		1
Catheterized / Incontinent of faeces		2
Doubly incontinent		3
Mobility		
Fully mobile		0
Restless / Fidgety		1
Apathetic		2
Restricted mobility		3
Inert / Traction		4
Chairbound		5
Special risks		
Tissue	Terminal cachexia	8
Malnutrition	Cardiac failure	5
	Peripheral vascular dis	5
	Anaemia	2
	Smoking	1
Neurological deficit	Diabetes / CVA / MS	4–6
	Paraplegia / Motor	4–6
	Sensory	4–6
Major surgery or trauma	Orthopaedic	5
	Below waist spinal	5
	On table > 2 hours	5
Medication	Steroids / Cytotoxics	4
	Anti-inflammatories	4
ADD UP TOTAL FOR THIS COLUMN		

General information		
Demographics		
Male		1
Female		2
Age 14–49		1
Age 50–64		2
Age 65–74		3
Age 75–80		4
Age 81+		5
Build (Body Mass Index = wt / ht²)		
Average:	BMI 20–24.9	0
Above average:	BMI 25–29.9	1
Obese:	BMI >30	2
Below average:	BMI <20	3
Visual assessment of skin risk areas		
Healthy		0
Tissue paper		1
Dry		1
Clammy		1
Oedematous		1
Discoloured		2
Broken / Spot		3
Appetite		
Average		0
Poor		1
NG tube / Fluids only		2
Nil by mouth / Anorexic		3
ADD UP TOTAL FOR THIS COLUMN		

Nutrition score: specific information	
Ability to eat	
Able to eat independently	0
Ill-fitting dentures / Chewing problems	2
Needs to be fed	3
Dysphagia	4
Symptoms	
Nausea / Vomiting	2
Diarrhoea	2
Confused	2
Depressed / Apathetic	2
Unintentional weight loss in last 3 months	
1 Stone	2
2 Stone	4
3 Stone	6
ADD UP TOTAL FOR THIS COLUMN	

Waterlow score	Nutrition score

INTERPRETATION

Waterlow score		Nutrition score	
1–9	Normal	1–5	Well nourished
10–14	At risk	6–10	Moderately nourished
15–19	High risk	11–15	Poorly nourished
20+	Very high risk	16+	Very poorly nourished

cian developed a frequency questionnaire and nutritional tool. The total sample size was reduced to 30 patients due to confusion or hearing difficulties.

The results demonstrated that the patients appeared to be adequately nourished before their admission. However, the women tended on average to have a poorer diet then men. Older men generally still have larger appetites than women. Of the sample, 20 developed pressure sores (80% of the patients who had undergone a hip replacement). The nutritional tool did not identify these patients. Lewis concludes that 'it may be prudent to attempt to identify patients who are at nutritional risk before they are admitted to hospital'. However, this is only possible for the patients who are being admitted electively. The issue of healthy diet needs to be addressed in outpatients when they are seen by the consultant so that the patients can be given instruction on a healthy diet at least 3 months before surgery.

Reynolds and Baine (1992), in a small study comparing patients with traumatic (low energy) fractured neck of femurs ($n = 20$) with iatrogenic (hip replacement) fractured neck ($n = 20$) of femur, showed that patients with traumatic fractures had statistically significant lower vitamin B_6 levels than patients admitted for elective surgery. This suggests that emergency admission patients had chronic poor nutrition before their fractures.

Burton score

The Nutritional Group at Queen's Hospital, Burton, developed a simple nutritional scoring system — the Burton score (Russell et al, 1998) — based on, and complementary to, the Waterlow score (*Figure 1*).

The Burton score utilizes the general information from the Waterlow score (Waterlow, 1988) such as demographics, body mass index (BMI), visual assessment of skin areas, and appetite, and adds nutritionally specific questions regarding the following:

1. Ability to eat independently
2. Ill-fitting dentures or chewing problems
3. Symptoms of nausea or vomiting
4. Diarrhoea
5. Confusion or depression
6. Apathy
7. Unintentional weight loss in the last 3 months of one, two, or three stones.

Each section is weighted with a score. The Waterlow-specific information and the nutritional information are added together to give the Burton score.

Table 3. Assessment of the Burton/Waterlow scores

The Burton and Waterlow scores were closely correlated and appeared to measure factors which indicate poor health status
The Burton score was superior to the Waterlow score for distinguishing patients who, in the opinion of a dietician, were poorly nourished in one of three areas (calorie intake, protein intake, or vitamin/mineral intake)
The Burton score was an effective measure of a patient's nutritional status and took account of calorie intake, protein intake and vitamin/mineral intake
The mid upper-arm circumference (an indicator of nutritional status) in men was more strongly correlated with the Burton score than in women. However, although it just failed to reach statistical significance there was a trend towards significance. This relationship once again suggested that the Burton score was an effective measure of nutritional status
The Burton and Waterlow scores are both valuable indicators of patients' needs. Although there was a strong concordance between assessments made with the two scores, there were also a significant number of cases where there was discordance. Therefore, the use of one score alone could result in an identifiable risk going unrecognized. It was, therefore, recommended that the Burton score be added to the Waterlow scoring during routine admission assessment. This is already being carried out for all new admissions

The nutritional team undertook a study of 263 patients on medical and surgery wards using the Burton/Waterlow scores. Assessments were conducted over a 3-month period and dieticians and an audit nurse recorded patients' dietary intake. The main findings are listed in *Table 3*.

The Burton score was devised as a simple tool for assessing nutritional status which has the benefit of using a system already well understood by many nurses. We believe this provides the assessment tool recommended by the King's Fund Report in 1992 (Lennard-Jones, 1992. Introduction of this type of screening system could produce significant benefits for patient care. Hospital-induced malnutrition is a common occurrence; it can be recognized and prevented. Nurses, doctors and all members of the multidisciplinary healthcare team can play a key role in its recognition (Dickerson, 1986).

CONCLUSION

All the literature reveals that early nutritional assessment is very important in the prevention of pressure sores. However, national guidelines do not exist on the recommended intake for an acutely ill patient. Furthermore, there are numerous nutritional tools being devised but not validated. A national tool needs to be approved. This may mean a compromise of one tool for the community and another tool for the acute sector, but this would afford continuity of nutritional care being delivered to patients. BJN

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KEY POINTS

- Observation of how much food patients eat is important when they are in hospital, home or nursing home.
- Many elderly patients are admitted with poor health, which has been present over a number of years, and have also not been eating correctly for years.
- Nationally agreed tools do not exist and there is danger that these tools will proliferate to become as numerous as the pressure risk assessment tools.
- The Burton score was devised as a simple tool for assessing nutritional status and has the benefit of using a system which is already well understood by many nurses.

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A comparison of healing rates on two pressure-relieving systems

Linda Russell, Tim Reynolds, Judy Carr, Amanda Evans, Margaret Holmes

Abstract

The authors have previously reported the preliminary results of a randomized-controlled trial comparing the relative efficacy of two pressure-relieving systems: Huntleigh Nimbus 3 and Aura Cushion, and Pegasus Cairwave Therapy System and ProActive Seating Cushion (Russell et al, 2000). Although both the mattresses and cushions were effective treatments for pressure ulcers, the Huntleigh equipment was demonstrated to be statistically more effective for heel ulcers, but no differences were demonstrated for sacral ulcers. This article gives a more detailed analysis of the 141 patients assessed using computerized-image analysis of the digital images of sacral ulcers captured during the trial and specifically discusses the healing rates and other patient characteristics. Ninety-eight per cent of ulcers examined were deemed superficial (Torrance grade 2a, 2b, 3). Precision of image analysis assessed by within- and between-batch coefficients of variation was excellent: calibration CV 0.93–1.84%; area CV 4.61–5.72%. The healing rates on the two mattresses were not shown to be statistically different from each other.

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Approximately 60% of all pressure ulcers develop in hospital (Dealey, 1994). Furthermore, at any one time, around 50% of patients are at risk of developing pressure ulcers (Dealey, 1997). Current estimates of the cost of pressure ulcers to the NHS are more than £320 million (Audit Commission, 1985), or £400–1000 million per annum (Moody, 1997). The Department of Health (DoH) states that prevalence of pressure ulcers is an excellent indication of quality of care (DoH, 1993) but the equipment needed to prevent hospital-acquired pressure ulcers is expensive and often in short supply.

To reduce the incidence of ulcers within available equipment constraints, the authors developed an evidence-based pressure ulcer prevention policy. In the process they discovered that despite the wide variety of pressure relief equipment on the market, the few clinical trials that have taken place have all been small and unable to produce the statistical evidence of efficacy or cost-benefit analyses required to found an evidence-based policy (Swain et al, 1992; Hitch, 1994).

The preliminary results of a randomized-controlled trial comparing the relative efficacy of two pressure-relieving systems: Huntleigh Nimbus 3 and Aura Cushion and Pegasus Cairwave Therapy System and ProActive Seating Cushion have been reported elsewhere (Russell et al, 2000). Although both types of mattresses and cushions were effective treatments for pressure ulcers, the Huntleigh equipment was demonstrated to be statistically significantly more effective for heel ulcers but no differences were demonstrated for sacral ulcers. We report here more detailed analysis of the computerized-image analysis of the digital images captured during the trial and specifically discuss the healing rates and other patient characteristics.

Traditionally, wound area has been measured two-dimensionally by multiplying its length and width. This assumes wounds are rectilinear, i.e. oblong. This assumption can give an estimate significantly at variance to the true area. Alternatives include tracing the wound on acetate, cutting out the resultant shape and weighing, sophisticated photography with planimetry or computer analysis of images, or tracings (Brohannan and Pfaller, 1983; Anthony, 1987; Majeske, 1992; Ahronic et al, 1993). Cameras have even been linked directly to computers to provide reproducible results (Palmer et al, 1989).

All wound area measurement techniques have their disadvantages: tracing can be time-consuming, planimetry can be slow and expensive and computer image analysis can suffer interobserver variability, e.g. owing to individual edge detection criteria (Anthony, 1987). Ruler methods (e.g. the Kudin ruler; Kudin, 1985) have been shown to underestimate wound area, in some cases by orders of magnitude (Plassmann, 1995). Additionally, the variability of ruler estimates is high.

In a research project, reproducibility of measurement is paramount, and therefore in our research we used an image-based protocol. Photographic methods have been validated against acetate tracing which has been shown to be superior to ruler-based methods (Thomas and Wysocki, 1990).

> One of the significant problems with trying to measure a wound is the natural curvature of the body as all the tools are designed to measure wounds as a flat object and consequently will be inaccurate... Furthermore, a camera angle of 20° to the perpendicular can result in a reduction of the measured area by approximately 10%...

One of the significant problems with trying to measure a wound is the natural curvature of the body as all the tools are designed to measure wounds as a flat object and consequently will be inaccurate (Melhuish et al, 1994; Bates-Jensen, 1995; Plassmann, 1995).

Furthermore, a camera angle of 20° to the perpendicular can result in a reduction of the measured area by approximately 10% (Palmer et al, 1989). Given standardization of image recording, computer analysis allows reproducible measurement of wounds. It is more reliable than manual measurements: 25% between observer coefficient of variance (CV) for repeat estimations carried out manually compared with 0.2% for computer analysis (Mekkes and Westerhof, 1992).

Taylor studied various shapes, i.e. circles, rectangles, polygons, traced by a computer programme with five volunteers: three male, two female, four right handed and one left handed (Taylor, 1995, 1997). A mouse was used to trace image outline, which was then stored and analyzed by the computer. The results demonstrated that an interobserver CV of 1.3–2.0% is achievable (Taylor, 1995, 1997).

Current data suggest that measurements of an ulcer's dimensions, exudate and tissue reaction (granulation/necrosis, etc.) provide valid indicators for monitoring changes over a time period. A study of 14 patients, seven with pilonidal sinus excision and seven with abdominal wound cavities after surgical procedures has been reported (Melhuish et al, 1994). Wounds were evaluated at weekly intervals using light measurements for the area, volume and depth. The wound edges were highlighted with a mouse, and the computer calculated the number of pixels in the area being studied.

Results demonstrated a correlation between volume and circumference assessed using the Gilman formula (Gilman, 1990). The authors noted difficulty in reproducible measurement of area and volume because of the wound locations. However, they were able to conclude that it is acceptable to monitor progress by assessing the wound circumference.

METHODS

Trial methodology

Data were analyzed from the randomized-controlled clinical trial of Pegasus Cairwave and ProActive Seating Cushion and the Huntleigh Nimbus 3 and Aura Cushion for the treatment of pressure ulcers (Russell et al, 2000). The trial collected data on 141 patients over 18 months. The entry criterion for the trial was presence of a pressure ulcer, Torrance grade 2 or greater (Torrance, 1983). All sacral ulcers were photographed digitally at weekly intervals. The recruitment, randomization, monitoring other trial procedures and preliminary results have been previously reported (Russell, 2000) and will not be further detailed in this article.

Digital images

All sacral ulcers in the trial were photographed, heel ulcers were counted but not recorded because heels are a curved surface and reproducible images were found to be impossible to achieve. Images were recorded using a Kodak 410 digital camera system and were recorded as a 32-bit, 1524 x 1012 pixel data. A standard L-shaped white scale with centimetre markings framed all ulcers. Digital imaging was used because no film was involved, thereby preventing not only loss of data during postal processing, but also variability in image colour due to film and chemical variation, as well as scanning inaccuracies.

To ensure reproducibility, we took standardized digital images, i.e. the patient lay on the same side (left or right) and in the same position. The surroundings and lighting were the same for each image and the camera was always positioned carefully. Uncompressed files were saved to camera, uploaded and white balance corrected against the scale using image acquisition software PhotoShop Plugin (Kodak, Rochester, USA) and Adobe PhotoShop version 5.0 (Adobe Systems Inc., USA) to remove lighting effect variation, and copied to compact disc (CD) for permanent storage. To ensure accurate length calibration, any rotation of the image was corrected so that the scale lay parallel to the frame.

Image analysis

This study analyzed only the sacral ulcers occurring during the trial. Digital images were analyzed using PC Image software (Foster and Findlay Associates, Newcastle-upon-Tyne) using a 'macro' which automatically assessed the ulcer length and breadth, area, and colour (hue, saturation and intensity). A macro is a recorded sequence of commands that are collected together and run as a single instruction. Stage 1 was calibration against the length scale. Stage 2 was identification by manual outlining of small ulcer areas and total ulcer area and a normal skin area with the mouse. Stage 3 was automatic assessment of each identified site of the area, location relative to the origin, and colour. Finally, all data were imported into a database. All individual measurements for each sacral ulcer area were then manually coded (S1, S2, S3...etc.) by comparing the location (X, Y coordinate data) with a printed photograph so that longitudinal changes in wound area could be tracked.

Precision of computerized analysis

Analytical precision was assessed by repeated analysis of two set images using standard techniques used to assess laboratory imprecision (Kringle and Johnson, 1986). To assess within-batch precision, repetitions were made in a single analysis session, and to assess between-batch precision, three test images were analyzed every time a new analysis session was completed.

Analysis of healing rates

Analysis of wound healing rates in clinical trials is challenging: depending on the method used for analysis it is possible to conclude whether wound A heals faster than wound B, heals at the same rate or heals slower (Gorin et al, 1996). Healing assessed by total area healed or percentage area healed can be adversely influenced by the initial wound area. Therefore, we utilized the linear growth rate of wound edge method suggested by Gorin, as wounds tend to heal inwards from the outer edge.

We made one alteration in that wound margin length is a fractal dimension, i.e. as one increases the precision of definition of the wound edge, the length continues to increase, e.g. if the distance around an island can be measured as 1 mile, this can be increased by taking the measurement into every inlet and bay, and then around every rock — meaning that the true distance is actually impossible to assess.

Consequently, we measured the area of each wound and assumed that the wound was a perfect circle: by applying the formulae for the area of a circle (πr^2) the radius could be determined and then the formula for the circumference of a circle ($2\pi r$), the estimated linear wound margin was obtained. Incremental (7-day) and total wound area changes for each identified wound ($\Delta A = A_{initial} - A_{next}$) were calculated and the linear daily wound edge growth was calculated thus:

$$\text{Wound progression} = \frac{\dfrac{\Delta A}{\textit{Circumference}}}{\textit{Time increment}}$$

The calculation for wound progression gives a negative number for a reduction in wound area (healing) and a positive number for increase in wound area. Values are reported in mm/24 hours.

Analysis of confounding medical conditions

To determine whether there were any significant differences in the patients randomized to each group which may have affected healing rates, e.g. if one group failed to heal, was this because they were more incontinent?), the medical conditions of patients admitted to the trial were evaluated. Specifically, we classified the reasons for admission into seven categories (*Table 1*) and compared the distribution of patients on each surface by χ^2 test. Similarly, continence status, mental status and nutritional status were also compared by χ^2 test (*Table 2*).

Table 1. Medical conditions causing admission to hospital

	Cairwave	Nimbus 3
Malignancy/terminal care	6	8
Cardiovascular	14	9
Cerebrovascular/Dementia	8	10
Infection	13	16
Orthopaedic	12	11
Wound care	10	10
Other medical	13	14

RESULTS

Patient characteristics

Table 1 shows the basic medical conditions resulting in admission to hospital. *Table 2* shows frequency of incontinence status, mental status, and nutritional status. χ^2 testing was used to compare the frequencies within each category with the null hypothesis that frequencies were similar in both groups. No statistically significant differences were demonstrable for reason for admission, mental status or nutrition state. Furthermore, admission type (emergency/

GP/other), bed frame (mesh/ridged/solid), frequency of nurse repositioning patients on the mattress, all showed no significant differences (raw data not shown). Repositioning was shown to have been carried out every 4 hours despite advice from mattress suppliers that longer intervals may be acceptable for some patients: turning frequencies are not specifically recommended as patients may need changing for reasons other than pressure area care.

A statistically significant difference was shown for incontinence. This demonstrated that there was a significant difference between patients on Nimbus and Cairwave equipment. A greater proportion of patients on the Nimbus bed were incontinent of either faeces or urine.

Table 2. Nursing assessments of incontinence, mental and nutritional status

	Cairwave	Nimbus 3
Incontinence		
Incontinent of urine	5	15
Urinary catheter	21	13
Incontinent of faeces and urine	11	15
Not incontinent	36	26
$\chi^2=9.005$; $P<0.05$		
Mental status		
Unknown	2	4
Disoriented	15	24
Confused	6	3
Lucid	47	37
Poor memory	3	1
$\chi^2=5.82$; P=N/S		
Nutritional status		
Unknown	1	2
Fair	37	34
Good	14	9
On fluids only	5	5
Reduced intake	16	19
$\chi^2=1.69$; P=N/S		

N/S = not significant

Table 3. Within-batch and between-batch precision coefficients of variation

Within-batch	
Calibration	1.17% and 0.93%
Ulcer area determination	4.76% and 5.53%
Between-batch	
Calibration	1.04%, 1.42% and 1.84%
Ulcer area determination	4.61%, 5.43% and 5.72%

Precision of image analysis

Precision estimates are shown for within- and between-batch image processing. For within-batch precision, estimates for two different images and for between-batch precision, estimates of precision for three images are shown (*Table 3*).

The coefficient of variation allows an estimate of how likely the value measured is to be the 'correct' result. For example, if the CV is 1%, then there is a 63% probability that the measurement made will be within 1% of the true value and a 95% probability that the result is within 2% of the true value.

Analysis of ulcer grades at entry and during trial

It must be noted that in the preliminary report of this study, it was stated that 30 (of 57) patients on Huntleigh Nimbus equipment and 33 (of 55) on Pegasus Cairwave equipment had sacral ulcers, 'completed' the trial alive, and demonstrated improvement in their sacral ulcers — the remainder of these groups did not improve (Russell et al, 2000).

Table 4 shows the total number of different ulcers of each grade (Torrance, 1983) at entry to the trial and the total number of different ulcers of each grade noted during the trial, for all patients and all ulcers which could be photographed twice, i.e. present at least 7 days. This definition included patients who died and, therefore, had not 'completed' the previous trial. There was no statistically significant difference in the numbers of patients who died on either mattress.

Consequently, there was a greater number of patients: comprising 64 Pegasus Cairwave patients and 59 Huntleigh Nimbus patients whose sores were evaluated to determine their healing rates. If a patient had two ulcer areas, this counted as two separate ulcers, which explains the considerably higher numbers of ulcer in this report compared with our previous report (Russell et al, 2000).

"Overall, the "at entry" data shows that there is no statistically significant difference between the area of grade 2a sores on the Huntleigh Nimbus and on the Pegasus Cairwave. When all ulcers are considered, the mean area on the Pegasus Cairwave remains similar but that on the Huntleigh Nimbus decreases. Again, this is not statistically significant"

For the purposes of our analysis, we divided Torrance grade 2 into grade 2a and grade 2b, such that grade 2a represents areas of persistent erythema with intact epidermis and grade 2b an area of persistent erythema with epidermal loss (Nixon et al, 1998). The total number of ulcer areas/patient at entry and in total are shown in *Table 4*. We have also evaluated the total number of sores at entry to the trial and the total number of ulcers ever present to determine whether there was any bias in recruitment or difference in the performance of the mattresses tested. The distribution of ulcer types was not significantly different at entry or later in the trial by χ^2 test ($P > 0.05$).

Table 4 shows that the total number of ulcers increased in both groups (at grade 2 especially) and that there appeared to a greater proportion of patients who developed more grade 2b ulcers on Pegasus Cairwave equipment. It was possible that this development of larger number of ulcers is because of a greater number of 'smaller ulcers', possibly due to the creation of ulcerated islands surrounded by non-ulcerated tissue developing as part of the healing process, i.e. a single area of grade 2b could be separated into two areas of grade 2b by development of an epithelial bridge which would then be called two ulcers.

Therefore, the median and mean area of ulcers at first appearance and on trial entry, for ulcer grades 2a and 2b, are shown. In addition, the total and mean sore areas per patient were also examined (data not shown) and demonstrated similar results. Overall, the 'at entry' data shows that there is no statistically significant difference between the area of grade 2a sores on the Huntleigh Nimbus and on the Pegasus Cairwave. When all ulcers are considered, the mean area on the Pegasus Cairwave remains similar but that on the Huntleigh Nimbus decreases. Again, this is not statistically significant.

Analysis of wound progression rates

Figure 1 shows graphically, and *Table 5* shows numerically, the sacral ulcer healing rates for grades 2a and 2b, with grade based on the first time a ulcer was assessed, with mean and standard deviation determined from data trimmed to exclude gross outliers. No statistically significant difference between the distributions of healing rates for grades 2a or 2b were shown by Wilcoxon-Mann-Whitney rank sum testing or by parametric statistical tests.

Table 4. Incidence and size of ulcers at entry to trial, and of all ulcers present long enough to have two photographs (within 7 days)

	Cairwave (At trial entry)	Cairwave (All ulcers)	Nimbus (At trial entry)	Nimbus (All ulcers)
Grade 2a	64	71	55	59
Grade 2b	66	107	52	73
Grade 3	7	10	0	1
Grade 4	1	1	3	3
Grade 5	0	0	1	1
Total ulcers	138	189	111	136
Total patients	64	64	59	59
Ulcers/patient	2.15	2.95	1.88	2.305
Median area of grade 2a ulcers (cm^2)	48.1	45.7	50.5	43.2
Mean area of grade 2a ulcers (cm^2)	58.5 ± 55.5	58.1 ± 61.7	63.4 ± 62.6	50.5 ± 39.8
Median area of grade 2b ulcers (cm^2)	0.27	0.27	0.20	0.27
Mean area of grade 2b ulcers (cm^2)	0.76 ± 1.15	0.62 ± 0.96	0.57 ± 1.01	0.56 ± 0.91

Length of stay

The overall mean (± sd) and median lengths of stay for patients with sacral ulcers completing the trial were 25.3 ± 15.9 days, median 20 days (Pegasus Cairwave) and 23.3 ± 21.7 days, median 16.5 days (Huntleigh Nimbus). The difference between the lengths of stay was tested by student's *t*-test and by Wilcoxon-Mann-Whitney rank sum testing and no statistically significant differences were demonstrable. Similarly, separately analysing the patients with grade 2a ulcers of grade 2b ulcers identified no statistically significant differences.

Cost-effectiveness analysis

No formal cost-effectiveness data are available, but there was no difference between either mattress in respect of the perceived nursing interventions required, dressings applied, length of stay, etc. Consequently, the only factors affecting comparative cost-effectiveness were the purchase/rental costs and energy consumption of the equipment.

DISCUSSION

In our original article, we reported that the patients on each mattress type were broadly similar in terms of age, Waterlow score, Burton score, average and highest grade of ulcer present on admission to trial, and length of stay (Russell et al, 1998, 2000). We can now report that there were no biases in terms of clinical reason for admission, mental state or nutritional status (see *Tables 1* and 2). There is, however, one area where a significant difference was demonstrated: incontinence. Significantly, fewer patients on the Huntleigh Nimbus equipment were continent than those on Pegasus Cairwave equipment. These conditions would be expected to result in a greater incidence of pressure ulcers, but no significant trend was demonstrable.

The wound healing rates (see *Table 5*) are interesting because the mean indicates that there is actually progression rather than regression, while the median indicates regression. This is the classic presentation of a skewed distribution in which, despite trimming of gross outliers, a small number of poor results can give a false impression of the overall picture. *Figure 1* makes this clearer because one gets the impression that both mattresses, overall, promote healing of grade 2a ulcers (as proven by the median healing rates). The similarity of lack of progression or regression for grade 2b is also evident from the graph. Graphically, it is obvious to the eye that the statistical proof of no significant difference between healing rates on either mattress is correct.

We express confidence in our results because the precision of analysis was shown to be extremely good. In clinical chemistry circles, analytical imprecision has long been considered important. In 1963, it was recommended that the maximum imprecision allowable for any assay in clinical use should be a between-batch CV of 10% (Tonks, 1963). Further, it was specified that any CV greater than 20% was medically useless (Elion-Gerritzen, 1980; Skendzel et al, 1985).

The meaning of a CV is explained in the results section. Since we were researching the effect of treatment we wished to evaluate small changes as precisely as possible. Computer image analysis, therefore, proved itself to be extremely effective, as the CV for wound area was no greater than 6%. Thus,

Figure 1. Sacral ulcer healing rates (mm/day).

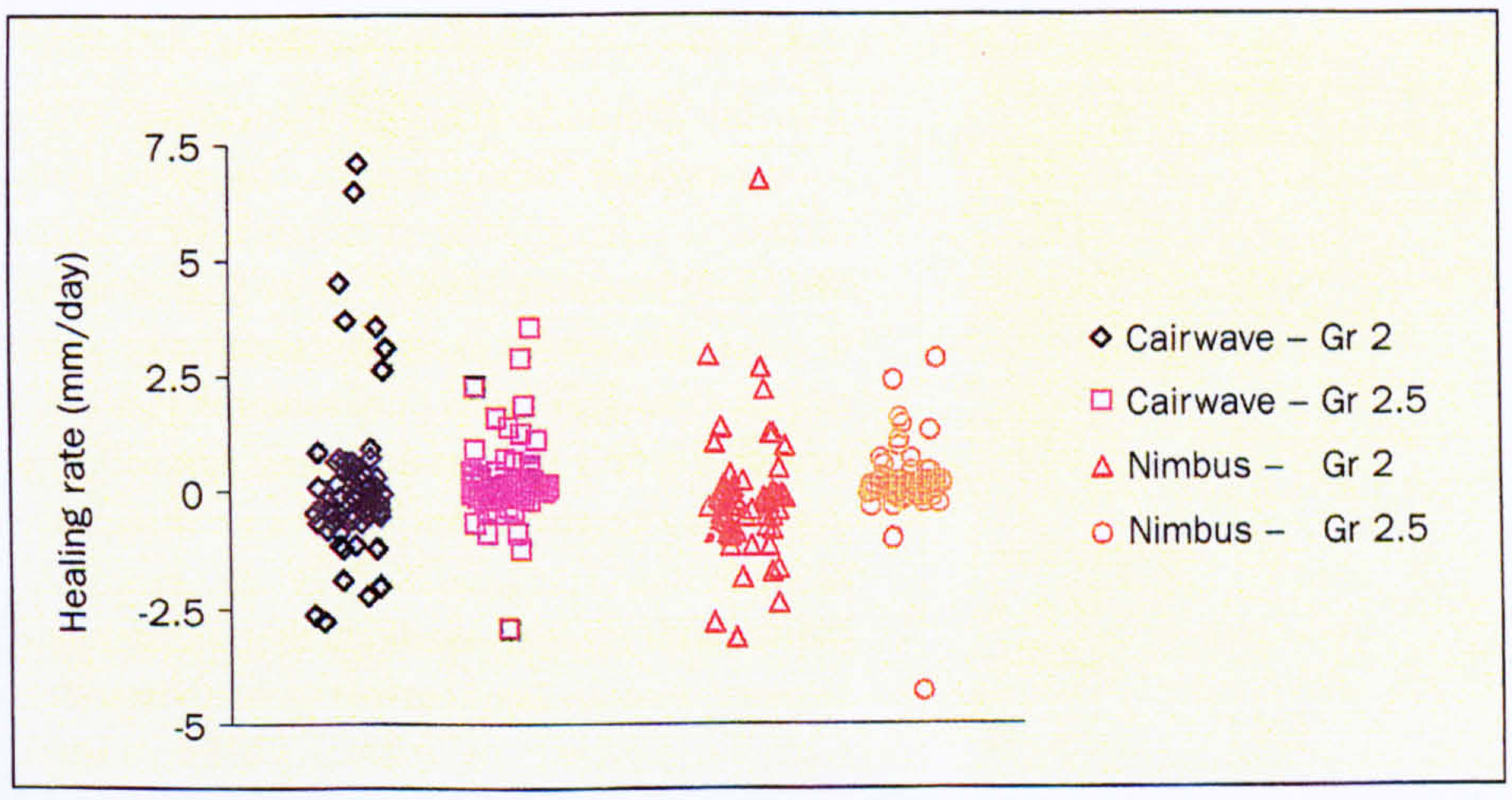

Table 5. Sacral ulcer healing rates from grades 2a and 2b

	Cairwave		Nimbus	
	Grade 2a	Grade 2b	Grade 2a	Grade 2b
Number of ulcers	67	104	62	73
Mean	0.17	–0.84	1.50	0.04
SD	1.72	1.07	1.22	2.18
5th percentile	–1.97	–0.72	–2.39	–0.36
Median	–0.16	–0.02	–0.29	–0.015
95th percentile	3.63	1.48	2.89	1.45

Statistical values describing healing rates on two systems by grade of pressure ulcer (see also *Figure 1*). Grades 3 and above excluded due to insufficient data. Values shown are wound margin movement in mm/24 hour. A negative value indicates reduction in wound area (healing), a positive value indicates wound increase. NB. Number of ulcers in this *Table* differs from number of ulcers in *Table 4* due to trimming of outliers; SD = standard deviation

KEY POINTS

- Traditionally, wound area has been measured two-dimensionally by multiplying length and width. This assumption can give an estimate significantly at variance to the true area.
- Digital imaging was used because no film was involved, preventing loss of data during postal processing, variability in image colour because of film and chemical variation, and scanning inaccuracies.
- Healing, assessed by total percentage areas healed can be adversely influenced by the initial wound area. Wounds tend to heal inwards from the outer edge. We utilized the linear growth of wound edge method suggested by Gorin.
- No statistically significant difference between the distributions of healing rates for grades 2a or 2b were shown by Wilcoxon-Mann-Whitney rank sum testing or by parametric statistical tests.

our maximum 95% confidence limit for any measurement was 1.96 x 6%, or approximately ±12%: a figure far better than would have been achieved by the 2-D rectilinear approximation method.

The reproducibility of our findings is important because it provides good confidence that the lack of clinically significant difference between the two systems is genuine and not because of random error introduced during analysis. Therefore, our results allow an estimate of the comparative cost-effectiveness of the two systems to be made.

In informal surveys of nurses on the trial wards, we found no differences in the perceived nursing interventions required, nurse time required, dressings applied or equipment breakdown frequency. As stated above, there were no differences in length of stay despite the apparently greater tendency for patients on Pegasus Cairwave equipment to develop extra sacral ulcers, indicating that in our study, the development of sacral ulcers is not a primary cost-driver.

In the planning stage of the clinical trial, 80% power to detect a 10% difference was projected. Owing to recruitment difficulties, the final study had 80% power to demonstrate a 20% difference between the two mattresses. It is clear from our results that no difference of this magnitude was found. The results do not prove that there is no difference between the mattresses. They do, however, show that it is highly unlikely that a difference of more than 20% in performance exists.

In the absence of formal cost-economic analysis, we identified that the main influences on cost-effectiveness of mattress systems are the length of stay, nursing interventions, wound dressings applied and equipment costs. We could identify no differences in length of stay, nursing intervention or dressings. Therefore, the purchase/rental, cost/energy consumption costs are the only differences between the two mattress systems which, at the time the trial was carried out, were marketed for patients at comparable risk/needing similar treatment. Hopefully, the data presented here will assist in the rational choice of pressure-relieving equipment. BJN

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Randomised controlled trial of two pressure-relieving systems

A study comparing the efficacy of two alternating-cell mattress and cushion combinations in the treatment of pressure ulcers in hospital patients

Pressure-relieving equipment; Pressure ulcers; Prevention policy

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Approximately 60% of all pressure ulcers are hospital-acquired, with annual costs to the NHS estimated to be more than £320 million[1] or around £400-1,000 million.[2] Some 50% of hospital patients are at risk of developing pressure ulcers, and prevalence is considered to be an excellent indicator of quality of care.[3] However, the equipment needed to prevent pressure ulcers is expensive and often in short supply.

Practitioners at the Queen's Hospital in Burton upon Trent have developed an evidence-based pressure ulcer prevention policy. It was found that, despite the wide variety of pressure-relieving equipment on the market, few clinical trials have taken place, and these have been small and unable to produce the statistical evidence of efficacy or cost-benefit required for the development of an evidence-based policy.[4,5]

The lack of reliable evidence to support the benefits of this expensive equipment is a problem for providers attempting to choose between the huge array of products. The research team tested two commonly used alternating-cell mattress systems together with pressure-relieving cushions, as seating is also known to be a significant factor in pressure ulcer risk. Normally the mattress in the unit was the Pegasus Airwave or Bi Wave.

Methods

Inclusion/exclusion criteria

Ethical approval was given by the South Staffordshire local research ethics committee. Patients admitted to the care-of-the-elderly unit at the hospital between August 17, 1997, and December 31, 1998, were included in the treatment trial if, on admission, they had pressure ulcers assessed at grade 2 or higher using the Torrance classification.[6]

The recruitment target was 100 patients per group, determined as 80% power to identify a 20% difference between the two mattress systems. Initially, the trial was planned to last 12 months, but it was extended to 18 months in order to recruit sufficient numbers of patients.

Patients were excluded if they were unwilling to participate; if randomised equipment was not available; if they had previously been included in the trial and were re-admitted with a pressure ulcer; or if they weighed more than 25 stone.

On admission to the study, subjects were randomly allocated to trial equipment. Pressure ulcers were treated using a standard protocol developed by the tissue viability nurse specialist and the tissue viability link nurses. The protocol, based on pressure ulcer guidelines, stipulated that a patient who had grade 2 pressure ulcers received an alternating mattress until the ulcers healed or they were discharged on to the advised surface.[7] No promotional contact between equipment suppliers and ward staff was allowed for the duration of the trial.

Equipment regimen

The equipment used was the Huntleigh Nimbus 3 with the Aura cushion (Group

ABSTRACT

The primary objective of this randomised controlled trial was to determine whether there were significant differences between two pressure-relieving systems. A secondary aim was to investigate whether the availability of extra pressure-relieving equipment would reduce the incidence of ulcers in an acute hospital setting.

A total of 141 patients in a care-of-the-elderly unit, who were assessed to have a high risk of developing pressure ulcers using the Waterlow score, were recruited; 70 were nursed using Huntleigh Nimbus 3 in conjunction with the Aura cushion (Group A), and 71 using the Pegasus Cairwave Therapy System in conjunction with the Proactive 2 Seating cushion (Group B). The main outcome measure was visual assessment, supported by a photographic record.

There were three main findings: for non-heel ulcers and overall improvement, there was no statistically significant difference between the two products tested; for heel ulcers there was a significant difference ($P = 0.019$) with more patients healing in Group A than in Group B.

The average length of stay of patients who completed the trial was 21.6 days (Group A) and 21.7 days (Group B) for patients

A) and the Pegasus Cairwave therapy system with the Proactive cushion (Group B). Seven sets of equipment were loaned by each manufacturer. Before the trial, all ward staff received training and one month's pre-trial use of the equipment was allowed for familiarisation. No additional pressure-relieving equipment was used during the trial.

Patients were turned according to manufacturers' recommendations: four-hourly for Group A, and once per eight-hour shift in Group B, or more often if requested by the patient or considered necessary by the nursing team.

Monitoring

The pressure ulcer status and risk status of all patients admitted to the hospital is routinely monitored using the Meditech HISS hospital information system. Data recorded include: whether a pressure ulcer is present on admission or develops during the patient's hospital stay – both were included in the study; the site; the severity; and progression/resolution of any ulcers. To ensure inter-observer reliability, ulcers were graded during the trial by one of three designated nurses who regularly work together.

All ulcers included in the trial were photographed at weekly intervals by a medical photographer using a high-resolution digital camera. Images were stored on compact discs, using codes that ensured image analysis could be carried out 'blind' to treatment group.

All patients were surveyed seven days after trial entry by an independent interviewer from the medical audit department, although patients with dementia were not included in the comfort survey.

TABLE 1. PATIENT CHARACTERISTICS ON ADMISSION

ALL PATIENTS			
Study group	**Average severity of ulcers**	**Highest severity of ulcers**	
Group A	2.46 (±0.49)	3.14 (±0.98)	
Group B	2.57 (±0.48)	3.17 (±0.81)	
	P = n.s.	P = n.s.	
PATIENTS WHO COMPLETED THE STUDY			
Study group	**Age**	**Waterlow score**	**Burton score**
Group A	83.9 (±5.91)	18.5 (±5.23)	12.3 (±4.49)
Group B	84.6 (±6.21)	19.1 (±4.75)	12.8 (±5.28)
	P = n.s.	P = n.s.	P = n.s.
PATIENTS WHO DIED			
Group A	84.5 (±6.79)	18.4 (±4.22)	12.8 (±3.28)
Group B	85.8 (±6.04)	20.1 (±6.40)	13.8 (±3.82)
	P = n.s.	P = n.s.	P = n.s.

n.s. = not significant

Comfort was assessed using digital analogue scales. Patients rated the mattresses and cushions for overall comfort on a 10-point scale derived from the British furniture industry standard scale which was then converted into a five-point scale to allow comparison with those developed by Gray.[8,9] Reference phrases ranged from 'I feel completely relaxed' to 'I feel unbearable pain', together with a five-point scale ranging from 'very uncomfortable' to 'very comfortable'.

Patients were asked to rate the mattresses for sleep on a five-point scale ranging from 'I had my worst night ever' to 'I had my best night ever'.

Statistical analysis

To prevent bias, randomisation of bed allocation and interim statistical monitoring to ensure ethical compliance co-ordination was undertaken by a member of the team who had no responsibility for direct patient care or knowledge of pressure-relieving systems. Monitoring of data collection and protocol compliance was carried out by another team member, 'blinded' to the statistical analysis.

All problems with the equipment and servicing requirements were recorded.

Data from patients who did not complete the trial are not included in the statistical analysis.

Results

Altogether, 183 subjects were recruited; of these 26 (16 in Group A and 10 in Group B) died during the course of the trial and a further 45 did not complete it. Of the 112 who completed the trial alive 57 were in Group A and 55 in Group B.

Of those who did not complete, 41 had their wounds photographed only once and were discharged too early for any assessment to be valid. Four patients withdrew from the trial (two did not like being photographed and two could not sleep on the alternating-cell beds).

Table 1 shows details of age, Waterlow score, Burton score (a nutritional assessment marker),[10] and ulcer severity on admission (as average of all ulcers recorded or the highest severity recorded). The average length of stay of patients who did not complete the trial was 5.4 days, compared with 21.6/21.7 days (Groups A/B respectively) for patients completing alive (range 1-121 days) and 29.7/24.3 days for patients who died.

Table 2 shows the response of pressure ulcers to treatment, showing improve-

completing alive (range 1-121 days) and for patients who died 29.7 days (Group A) and 24.3 days (Group B).

Routine monitoring showed that, before the trial, the incidence of hospital-acquired pressure ulcers (Torrance grade 2+) was 0.2%; during the trial, this dropped to 0.13%. The study showed differences in the efficacy of different mattress products; with a sufficiently large study, it is possible to demonstrate statistically significant results.

Provision of extra pressure-relieving equipment can reduce the incidence of pressure ulcers but may not influence length of stay.

TABLE 2. ULCER HEALING

Improvement factor	Completed alive Yes	No	Completed alive + died Yes	No
OVERALL				
Group A	53 (96%)	2	65 (93%)	5
Group B	52 (91%)	5	65 (91%)	6
χ^2	1.260		0.08	
	P = 0.26		P = 0.78	
SACRAL ULCERS				
Group A	33 (60%)	22	36 (51%)	34
Group B	30 (53%)	27	32 (45%)	39
χ^2	0.62		0.57	
	P = 0.44		P = 0.45	
HEEL ULCERS (12 MONTHS)				
Group A	21 (60%)	13	26 (57%)	20
Group B	12 (40%)	18	13 (33%)	27
χ^2	3.02		4.98	
	P = 0.082		P = 0.025	
HEEL ULCERS (FINAL – 18 MONTHS)				
Group A	24 (59%)	17	30 (55%)	25
Group B	17 (39%)	27	19 (33%)	39
χ^2	3.37		5.46	
	P = 0.067		P = 0.019	

ment in all ulcers, in sacral ulcers and in heel ulcers. The heel ulcer response is shown for two time periods – 12 months and final, that is 18 months. The trial was extended to 18 months because statistical significance was not attained in the completed alive group after 12 months. Significance was still not shown, but both results are given to indicate that with further extension and larger recruitment numbers, it is possible that a P-value <0.05 would have been achieved.

The comfort scores and corresponding comments for each question are shown in Table 3. Responses ranged from 1 (best) to 5 (worst). Where a patient selected more than one description, the mean score was used. Since the results came from a restricted ordinal scale, statistical evaluation was carried out non-parametrically using the Wilcoxon rank sum test. The scales used in the research questionnaire were not directly consistent and the groupings shown reflect the mathematical transform used.

Equipment performance

Few difficulties were encountered. Initially, there were some problems with the welds in the Group A cushion (Aura); this product had been released for the trial itself, and all problems were resolved after the first month. Two Group A mattresses (Nimbus), 10 Group A seat cushions (Aura), seven Group B therapy systems (Cairwave) and six Group B cushions (Proactive) required repair. All other mattresses and cushions were routinely serviced after one year.

Incidence monitoring

Routine incidence monitoring was carried out during the trial. Before the trial 0.2% of patients developed hospital-acquired pressure ulcers (Torrance grade 2+). During the trial, this figure dropped to 0.13%. This was attributed to improved education, vigilance and equipment availability.

Discussion

The project plan assumed an average length of stay of 18 days and 100% occupancy for the trial equipment (14 beds in all). However, it was not possible to maintain 100% occupancy. Additionally, some seriously ill patients occupied trial beds for considerably longer than expected, increasing the average length of stay to approximately 22 days. The death rate was also higher than expected.

The available data were examined after 11 months to determine whether the trial should be extended; no information was released to companies or to the nurses involved in the trial at this point.

It was found that the mattresses were equally efficient. Their use resulted in general improvement and healing of sacral ulcers; it was extremely unlikely, therefore, that statistically significant differences in efficiency would be found between the two mattresses.

Group A mattresses showed a statistically significant superiority with respect to heel ulcers. However, the numbers in the group which completed the trial alive were insufficient and it was estimated that if the trial was extended for a further six months, a statistically significant number of patients could be discharged alive.

After 18 months of data collection, it was found that there were again no statistically significant differences between the mattresses in the overall improvement or healing of sacral ulcers. When heel ulcers were considered, however, the difference between the two systems remained statistically significant, and the trend of results and P-values suggests that a further extension would have resulted in a statistical significance for the 'discharged alive' subgroup rather than for only the entire patient sample. This implies that the special heel pressure-reduction system of the mattress used in Group A may be effective in promoting healing.

Comparability of patient groups

One possible explanation for the differences found would be that the randomisation procedure had failed, and that all the patients who were most severely ill had been placed on the bed which appeared to perform least well. Alternatively a lack of difference could result because the most severely ill patients were nursed on a better performing surface but the severity of their conditions masked the benefits of that surface. To fully answer this proposition requires the completion of the image analysis phase of the project. Initially, it is practical to examine baseline patient data only in terms of age, Waterlow score, Burton nutrition score and severity of ulcer on admission to the trial. Table 1 shows that there were no significant differences between the patient groups.

Length of stay

Little can be said about length of stay. This was dictated by each patient's medi-

TABLE 3. PATIENT ASSESSMENT OF MATTRESS/CUSHION COMFORT

Comfort scoring system

Score	Questions 1a and 3a	Questions 1b and 3b	Question 2
1	I feel completely relaxed I feel perfectly comfortable	Very comfortable	I had my best night ever
2	I feel quite comfortable I feel barely comfortable	Comfortable	I was quite comfortable
3	I feel restless and fidgety I feel cramped	Adequate	I slept all right
4	I feel stiff I feel numb (pins and needles)	Uncomfortable	I was a bit uncomfortable
5	I feel sore and tender I feel unbearable pain	Very uncomfortable	I had my worst night ever

Patient group	Question 1a	Question 1b	Question 2	N	Question 3a	Question 3b	N
Group A (completed)	1.71 (±0.68)	2.48 (±1.32)	2.81 (±0.96)	29	1.80 (±0.69)	2.13 (±1.31)	16
Group B (completed)	1.94 (±0.82)	2.04 (±1.30)	2.46 (±0.92)	24	2.07 (±0.91)	2.85 (±1.37)	17
	P = not significant	P = not significant	P = not significant		P = not significant	P = not significant	
Group A (discontinued)	2.33 (±1.81)	2.25 (±1.89)	2.50 (±1.0)	4	1.56 (±0.47)	2.00 (±1.41)	2
Group B (discontinued)	2.51 (±1.04)	3.50 (±1.69)	3.56 (±1.12)	8	1.94 (±1.05)	2.25 (±1.89)	4

* Questions 1a and 1b refer to mattress comfort; Question 2 asked about sleep; Questions 3a and 3b refer to cushion comfort

cal condition. There was a continuum of stays and the trial did not have a major effect on delaying discharge.

Comfort

Few reports in the nursing literature deal specifically with the comfort of pressure-relieving systems. Often data have been collected by nurses who have their own perceptions of whether or not a bed is comfortable. Furthermore, assessments of comfort have often been made before the patient has become used to the bed's characteristics, or there has been no indication of the delay before the survey was carried out. This study used a digital analogue scale as described by Gray.[8,9] Comfort data were collected by the clinical audit department; the auditor had no understanding of the different types of bed, so could not exhibit bias. No statistically significant differences were found between the two mattresses tested.

Conclusion

The study has shown that both mattress systems are effective treatments for pressure ulcers. But no control group was used, and so it cannot be said whether more ulcers would have developed in patients using a standard mattress.

Both mattress/cushion combinations provided an overall improvement in more than 90% of patients and healing of approximately 50% of sacral ulcers. However, it has been shown that the Nimbus mattress is more effective for treatment of heel ulcers (55% healing) than the Cairwave system (33% healing). The significance of this finding to the NHS is not clear.

As the average length of stay in both patient groups was approximately 21.5 days, it appears that the presence or absence of a ulcer did not affect the discharge of the patient. There was also no clear difference between the mattresses or cushions for comfort scores. Other factors may be more important when choosing a mattress – this will be dealt with in a future paper when cost-benefit analyses have been completed.

The NHS spends large amounts of money on pressure ulcer prevention and treatment but has no reliable evidence on which to base purchasing decisions. Randomised trials to produce the required evidence are possible but need considerable input of resources because there is significant 'wastage' of recruits into trials in the necessary patient group.

Significant differences in the performance of pressure-relieving equipment may be demonstrated. These may not affect length of stay, and other factors, such as nursing interventions required, ease of use, and cost, may be more important when selecting equipment. Improved availability of pressure-relieving equipment can reduce overall hospital incidence of pressure ulcers. ■

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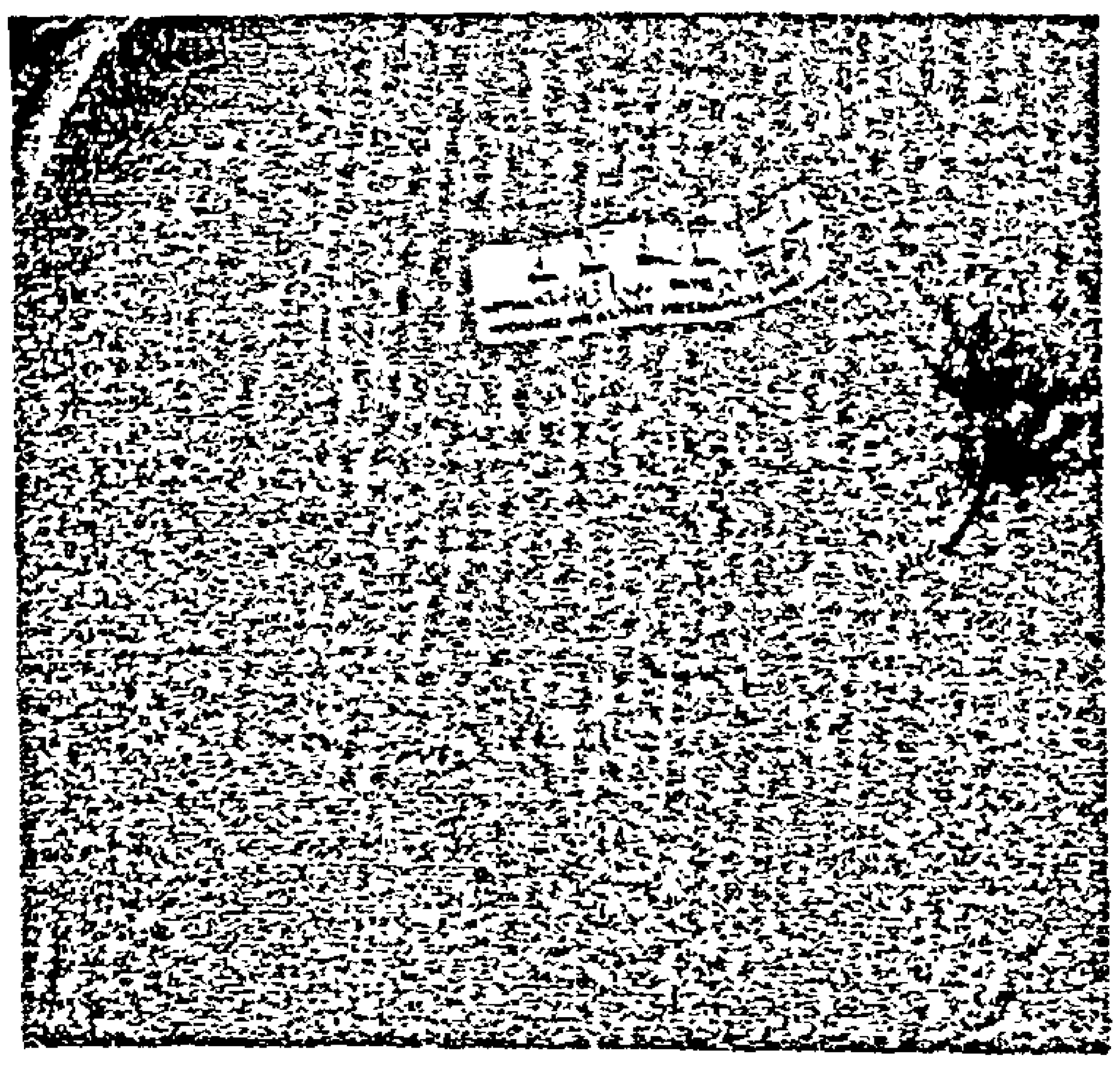

Ridge marks, which are caused by lying on a matted fleece, create high capillary pressure

Bootees are often used to protect the heels, but there is no evidence to support this

The sheepskin myth

LINDA RUSSELL explains why fleeces should be used only as a comfort aid, and never for pressure prevention

Artificial sheepskins were once routinely used for pressure ulcer prevention because they were inexpensive and readily available. But this ritualistic practice was not based on evidence and the limitations of their use were never considered.

There are still no guidelines on the use of sheepskins as a comfort aid within a pressure ulcer prevention framework. There is also no evidence to show that they reduce the incidence of pressure ulcers as a result of direct pressure relief (Dealey, 1991).

Some nurses still use sheepskins without realising that they provide no pressure reduction, only comfort, and that their use could actually result in a pressure ulcer.

WOUND HEALING RESEARCH UNIT/UNIVERSITY OF WALES COLLEGE OF MEDICINE

History of use

Most hospital patients are over the age of 75 and therefore at risk of developing pressure ulcers as a result of various intrinsic and extrinsic factors.

When sheepskins were first introduced they were recommended, in conjunction with two-hourly turns, for immobile patients with fragile skins.

Fleeces were originally used for pressure relief, but they were expensive and difficult to maintain. Artificial sheepskins were then introduced because they cost less and were easier to maintain (Dealey, 1991). They were soon readily available from most hospitals' laundries and were easy to obtain in the community.

Implication for practice

It is important that nurses realise fleeces should not be used as a substitute for two-hourly turns or a mechanical bed, which would be negligent in view of the evidence provided by the Medical Devices Agency (MDA, 1994).

Its report states that sheepskins should not be regarded as a pressure-relieving device but as a comfort aid because they provide inadequate protection on sacrum and hips and are of limited use on heels and elbows.

As comfort aids, sheepskins have some advantages. They reduce friction and absorb moisture and perspiration, helping to prevent skin maceration (Dealey, 1990), and promote comfort as they conform to the patient's shape (Denne, 1979).

But even when they are used as comfort aids, nurses should be aware that there are a number of potential disadvantages. Laundering artificial sheepskins results in a matted, lumpy surface that does not provide any pressure relief (Anthony, 1996).

If matted fleeces are placed under patients they can form ridges, which create high capillary pressure (Denne, 1979). Such ridge marks may be visible on the patient's skin, particularly on the buttocks and bony hips.

Increasing the mean capillary pressure to above 32mmHg causes capillary occlusion, initiating tissue death and the development of a pressure ulcer (Russell, 1998).

KEY WORDS
- Pressure ulcers
- Pressure relief
- Sheepskins

A further risk is that sheepskins can act as a reservoir for infection (Jackson, 1983).

Taking this evidence into account, it is clear that sheepskins should be used only as a comfort aid. Natural fleeces are recommended in preference to artificial sheepskins and any fleece that is clumped or matted must be discarded to guard against ridge formation. Fleeces should always be laid flat.

Conclusion

The nurse's contribution to the prevention of pressure ulcers is paramount (Cormack, 1985) and the key to prevention is in ensuring that a full and correct assessment of the patient's risk status is made and that adequate and appropriate pressure relief is then provided.

Patients who are unable to move themselves in bed or in a chair should not be placed on sheepskins (Dealey, 1991). They should be provided with a patient support system which ensures that they receive regular pressure relief. The only time a sheepskin should be selected for a patient is as a comfort aid.

Nurses are accountable for their actions and any omission of care through lack of knowledge that endangers the patient may be seen as negligence.

Nurses should strive to practise evidence-based nursing and should not follow ritualistic practices. If they know sheepskins can contribute to pressure ulcers but continue to use them for pressure relief, a court of law could find them guilty of negligence. NT

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The importance of patients' nutritional status in wound healing

Linda Russell

Abstract

Good nutritional status is essential for wound healing to take place. Ignoring nutritional status may compromise the patient's ability to heal and subsequently prolong the stages of wound healing. Glucose provides the body with its power source for wound healing and this gives energy for angiogenesis and the deposition of new tissue. Therefore, it is vital that the body receives adequate amounts of glucose to provide additional energy for wound healing. Fatty acids are essential for cell structure and have an important role in the inflammatory process. Wound healing is dependent on good nutrition and the presence of suitable polyunsaturated fatty acids in the diet. Protein deficiency has been demonstrated to contribute to poor healing rates with reduced collagen formation and wound dehiscence. High exudate loss can result in a deficit of as much as 100 g of protein in one day. This subsequently needs to be replaced with a high protein diet. Vitamins are also important in wound healing. Vitamin C deficiency contributes to fragile granulation tissue. There is a correlation between low serum albumin and body mass index (BMI) and the development of pressure ulcers. Also, low serum albumin and high Waterlow score have a positive association. The body automatically renews tissue while we are asleep but this does not mean that protein synthesis does not take place during our wakeful hours. Holistic assessment of nutrition and early detection of malnutrition are essential to promote effective wound healing.

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Wound healing is an intricate process and is the body's natural response to trauma. When this process is delayed or slowed, problems such as wound infections and keloid scarring are more likely to occur. Patients require adequate levels of protein, vitamins, fats and minerals to support wound healing (Morison et al, 1997). A patient with partial- or full-thickness burns or injuries will require a greater calorie intake.

The Panel for the Prediction and Prevention of Pressure Ulcers in Adults (1992) states that patients with pressure ulcers require 30–50 kcal and 1.25–1.50 g protein per kg body weight daily. A patient with a grade 3–4 pressure sore requires 2 g per day of protein (Chernoff and Milton, 1990). By comparison, the estimated average protein requirements for a 50–55-year-old male are 53 g/d, and for a female 46 g/d (Department of Health (DoH), 1991).

Wound healing is a complex process and nutrition plays a crucial role in the formation of new tissue. It is suggested that:

> **'Alteration in nutritional status or intake preceding or during injury may clearly alter the normal wound healing response'**
> *(Pinchcofsky-Devin, 1994).*

If the body's defences are low, replacement of tissue will be slower. Neglecting the nutritional health of the individual may totally compromise all the wound management undertaken (Wallace, 1994).

The body's response to a wound sustained through trauma, surgery or injury is to increase protein requirements. Initially, there is a fall in the metabolic rate in response to the trauma, but then it will rise again provided enough protein is available from the patient's reserves. As a result, fat and lean body mass will be broken down to provide extra energy. This is known as a catabolic state (Guest and Pearson, 1997). After surgery, additional nutrition will be required for wound healing. It is suggested that:

> **'Best surgical and nursing care available will not heal the wound if there is inadequate nutritional substrate to make new tissue'**
> *(Pinchcofsky-Devin, 1994).*

It is well established that improved nutritional status will improve healing (Holmes et al, 1987; Guest and Pearson, 1997). However, a poor nutritional intake is often found in patients who develop pressure ulcers and can result in delayed wound healing. This can result in a continuous cycle if it is not broken.

A patient who is malnourished can be given many forms of energy supplements. One of the most concentrated energy sources is fat, which has twice the amount of calories per

> As a result of an injury, the body responds by developing hyperglycaemia, induced by increased glucagon and adrenaline and a reduction in insulin, which increases glycogenolysis in the liver. This is part of the body's survival mechanism to supply it with additional energy.

gram than carbohydrates, e.g. cakes, biscuits and chocolates. The patient may, or may not, find these foodstuffs more desirable than nutritional supplements or drinks (Guest and Pearson, 1997).

GLUCOSE

Glucose provides the body with vital energy. In a wound, the cellular infiltrate of leucocytes and macrophages use glucose for aerobic glycolysis, which provides the energy for the production of factors that stimulate fibroblast production and collagen synthesis (McLaren, 1991). As a result of an injury, the body responds by developing hyperglycaemia, induced by increased glucagon and adrenaline and a reduction in insulin, which increases glycogenolysis in the liver. This is part of the body's survival mechanism to supply it with additional energy.

Depending on the extent of the injury, the need for extra energy varies. Wilmore (1977) demonstrated that wound glucose utilization reached 175 g per day in the case of patients with 42% burns.

Small wounds produce little effect on the metabolism, but extensive injuries such as burns can cause a significant rise in energy expenditure and hence requirements (Meyer et al, 1994). The effective production of energy depends on the body's capacity for aerobic metabolism, supported by angiogenesis — new blood vessels of short intercapillary distances, that are formed by the process of angiogenesis (endothelial buds that lay down), form new granulation tissue (Madden, 1983; Morison et al, 1997).

FATTY ACIDS

The role of fatty acids in the inflammatory response and tissue formation is becoming increasingly understood. Polyunsaturated fatty acids (PUFAs) are responsible for integrity of cell membrane structure and function. The release of membrane eicosanoids, chemicals involved in the inflammatory response, sends the biochemical message to initiate wound healing.

The metabolism of PUFAs produces prostaglandin E_3 and leukotrienes, which have vasodilatory and anti-inflammatory actions. The ω-6 PUFA metabolites include prostaglandins E_2 and I_2, which help mediate the inflammatory response, platelet aggregation and vasoconstriction (McLaren, 1991; Morison et al, 1997). Immunocompetent cells can synthesize eicosanoids from PUFAs, but this depends on the availability of ω-6 PUFA in the cellular pool. In turn, this activity is dependent on the nutritional intake, and this affects the phospholipase activity (Morison et al, 1997).

The ω series of polyunsaturated fatty acids, e.g. eicosapentaenoic (20:5ω-3) and docosahexaenoic (22:6ω-3) can be found in fish oils (Edwards et al, 1995). Increasing ω-3 PUFAs' dietary manipulation could result in reduced incorporation of ω-6 PUFA, thus reducing prostaglandin E_2 (PGE_2) production and resulting in altered T cells proliferative response, which could potentially benefit wounds that are in a persistent state of clinical inflammation caused by overactive macrophages (Cerra, 1991). This may occur where there is persistent inflammation, partly caused by the overactivity of macrophages (McLaren, 1991).

Gottslich et al (1990) demonstrated that an enteral feeding formula containing ω-3 fatty acids reduces the incidence of wound infection after burns. Omega 3 fatty acids also contain micronutrients, e.g. zinc, iron and copper, which may also contribute to healing.

Further research is required to determine the therapeutic dose of PUFA that is required to optimize effective healing in all types of wounds (Morison et al, 1997).

PROTEIN

A high protein diet is advantageous in the healing of pressure ulcers in long-stay elderly patients (Breslow and Bergstrom, 1994).

Protein requirements for an acutely ill patient are 1.5–2.5 kg in order to avoid negative nitrogen balance, which would place the patient in a state of anabolism (Chernoff and Milton, 1990). However, this may not necessarily happen in patients who are critically ill. Patients given high protein diets may require a high fluid intake to prevent renal failure (Pinchcofsky-Devin, 1994).

Protein deficiency contributes to poor wound healing by prolonging the inflammatory process, impairing collagen synthesis, and increasing the risk of wound dehiscence. A further problem encountered is secondary oedema due to hypoalbuminaemia — low protein levels for a very long period of time, which can be a long-term sequel to protein malnutrition (Morton, 1995).

Wound healing requires a large amount of energy because of the synthesis of the components needed for tissue repair. All the nutrients are transported around the body in the blood supply, which has to be adequately oxygenated. Many elderly patients have an underlying pathology, such as poor blood supply and reduced oxygen carriage, owing to their age. Wounds that are compromised by poor blood supply heal slower than well perfused wounds.

Albumin provides a source of amino acids for a healing wound. Cells can acquire albumin from the intravascular and extravascular compartments because albumin is freely permeable across cell membranes. At the site of injury, permeability may be increased, thus increasing plasma protein availability which appears to facilitate wound healing (Powanda and Moyer, 1981). Copious wound exudate can use as much as 100 g of protein per day (Thomas, 1994). Therefore, the patient's diet will need to compensate for this loss.

Oxygen expenditure of the body is increased during sleep and causes catabolism (Shapiro et al, 1993). Tissue renewal also takes place while we are asleep (Adam and Oswald, 1983). Growth hormone is released during sleep, aiding wound healing, as well as resting the patient's body (Adam and Oswald, 1983). Protein synthesis also occurs during the wakeful hours, and this enables the restoration of body tissue, but plenty of sleep and rest are necessary to promote wound healing.

VITAMINS

Alvarez and Gilbreath (1982) suggest that vitamins play a vital role in wound healing. Vitamin supplements may need to be increased by 10–20 times the normal recommended dose. The reason for this increase is the amount excreted by the body, reduced absorption and drug interaction, as well as their utilization in the increased metabolic process during wound healing.

Vitamin C

Vitamin C is vital for collagen synthesis. However, the role of vitamin C is not fully understood:

> **'...only that it is a stimulant for fibroblast cell division and subsequently collagen synthesis'**
> **(*Pinchcofsky-Devin, 1994*).**

In vitro studies have demonstrated increased uptake of vitamin C during phagocytosis (Shilotry, 1977; Leibowitz and Seigal, 1978). Vitamin C may increase the activity of leucocytes and macrophages to the wound. In vitro studies also showed that ascorbic acid may increase the activation of leucocytes and macrophages at, and attraction to, the injury site (Shilotry, 1977; Leibowitz and Seigal, 1978).

Goode and Burns (1992) demonstrated a connection between low concentrations of leucocytes, vitamin C and pressure ulcers in patients with fractured neck or femur injuries. Vitamin C

'...trace elements, such as zinc, copper and iron, play an important role in wound healing, as many are co-factors for enzymes involved in the process of new tissue formation...there is no overall factor that underpins the effects of wound healing, and further research is still needed as to the key micronutrients involved.'

supplementation has demonstrated that more rapid healing of pressure ulcers took place (Taylor et al, 1994). An explanation for this may be that the patients were in a deficient state. However, there has been little research into this apparent relationship, probably because of difficulties in measuring the levels of vitamin C.

Those patients at risk of pressure ulcers and who were poor eaters had an intake of significantly less vitamin C than patients who did not sustain pressures ulcers (Bergstrom and Braden, 1992). Vitamin C deficiency causes prolonged wound healing because of increased capillary fragility (Irvin and Challopadhyay, 1978).

Vitamin C deficiency increases the risk of wound dehiscence and contributes to fragile granulation tissue. Vitamin C is another vital co-factor for enzymes concerned with collagen synthesis (Casey, 1998). Open wounds require a great deal more collagen and new capillary growth. This process is dependent on the patient's nutritional status being favourable in order to produce healthy granulation tissue (Flanagan, 1998).

Vitamin A

Vitamin A stimulates differentiation in fibroblasts and collagen synthesis, thereby quickening the healing process and increasing tensile strength (Pinchcofsky-Devin, 1994). Another function of vitamin A is a humoral defence mechanism to help fight wound infections locally or systemically. Vitamin A compensates for the catabolic effect that glucocorticosteroids exert on wound healing (Ehrlich and Hunt, 1968).

Greenwald (1990) demonstrated that vitamin A enhances the healing of tendons. Vitamin A used topically can enhance epithelization (Smith et al, 1986).

Vitamin E

Vitamin E facilitates wound healing by enhancing the immune response. However, the role of this vitamin in wound healing is controversial as some reviews state it is harmful in vitro on tendon healing (Greenwald, 1990), while others say it is beneficial (Morton, 1995).

Vitamin E prevents lipid peroxidation of PUFAs in cell membranes by oxygen free radicals, thereby assisting anti-oxidant defence and wound healing (McLaren, 1991).

Decreased levels of vitamin E are associated with shortened lifespans of red and white blood cells (Pinchcofsky-Devin, 1994). A daily dose of vitamin E should not exceed 67 mg, as a higher dose can cause fibrosis, which subsequently delays wound healing (Taylor and Goodinson-McLaren, 1992).

Vitamin K

Vitamin K is known for its role in haemostatic clot formation over the injury site. It is a prerequisite for wound healing (Pinchcofsky-Devin, 1994).

Vitamin B complex

Several vitamins form the Vitamin B complex: thiamine/riboflavin, pyridoxine, folic acid and pantothenate (Chernoff, 1996). They have various roles:

- Assisting leucocytes and antibody formation
- Intermediary roles in metabolism
- Assisting essential co-factors in enzyme activity.

Thiamine/riboflavin and pyridoxine are important in the formation of collagen matrix (Alvarez and Gilbreath, 1982).

Vitamin B_6 assayed by high performance liquid chromatography (HPLC) has been demonstrated to be statistically lower in patients who fracture their hip in low impact falls than in patients whose hip fractures had elective surgery (Reynolds and Baine, 1992), suggesting that further research into interaction of these two vitamins may be needed.

TRACE ELEMENTS

It is well documented that trace elements, such as zinc, copper and iron, play an important role in wound healing, as many are co-factors for enzymes involved in the process of new tissue formation (Morison et al, 1997). There is no overall factor that underpins the effects of wound healing, and further research is still needed as to the key micronutrients involved.

It is stated that:

> **'Zinc status does not appear to be a significant factor in the development of pressure sores'**
> ***(Lewis, 1996).***

However, zinc therapy has also been demonstrated to be of benefit in patients with poorly healing surgical wounds (Henzel and DeWeese, 1970). Currently, there are insufficient studies to draw any conclusions as to the role of zinc in the healing of pressure ulcers.

Iron is necessary for the formation of collagen and transportation of oxygen to the tissues. Copper is required for the collagen matrix. An important fact is that erythrocyte production requires both copper and iron (Pinchcofsky-Devin, 1994). Guest and Pearson (1997) have shown that copper increases tensile strength of collagen.

To optimize wound healing, sufficient protein, energy, vitamin and mineral requirements have to be available or else corrected by nutritional supplementation. It is suggested that:

> **'Nutrition assumes an equal footing with other time honoured pathogenic considerations in wound prevention and treatment'**
> **(*Pinchcofsky-Devin, 1994*).**

SERUM ALBUMIN

Serum albumin values represent the body's albumin production and breakdown balance. A certain amount of extracellular albumin is stored in the skin and the rest in the muscles and viscera. Low serum albumin level results from decreased synthesis, increased catabolism and excessive loss into tissues. Most cases of decreased serum albumin are caused by protein malnutrition. When a patient has inadequate calorie intake but lacks protein in the diet, adult Kwashiorkor-like malnutrition may occur (Pinchcofsky-Devin, 1994).

A connection between serum albumin and the formation of pressure ulcers has not been shown (Bergstrom and Braden, 1992).

Strauss and Margolis (1996) have stated that:

> **'Recognizing deficits in the indices before they reach values that may reflect and jeopardize healing may help minimize morbidity and mortality in the population.'**

Anthony et al (2000) carried out a prospective study of 773 patients over the age of 64 years with a hospital stay of at least 1 week. Using the Hospital Information Support System to explain the data, patients' Waterlow scores, serum albumin levels, and sodium levels were analyzed using SPSS for logistic regression and discriminate analysis. A ROC (receiver operating characteristics) curve was used for sensitivity and specificity of the Waterlow scores at various thresholds. It was statistically demonstrated that high Waterlow scores and low serum albumin were strongly correlated ($P<0.001$) for patients who developed pressure ulcers. This study recommends that serum albumin can be assessed to give a better predictive power to the Waterlow score and can also provide greater sensitivity to identify patients who will develop a pressure ulcer.

BODY MASS INDEX

Rudman and Feller (1987) demonstrated the relationship between an annual death rate and percentage of ideal body weight (IBW).

Patients with actual body weight >100% of IBW had an annual death rate of 9.8%, compared with an annual death rate of 26.3% for those patients with an actual body weight of <80% of IBW. An IBW of <85% has been associated with numerous problems related to malnutrition (Harvey et al, 1981).

The surface area of a pressure ulcer is inversely related to the body mass index (Breslow, 1991). The importance of oral supplementation is that when used correctly it can improve wound healing and avoid the need for enteral feeding (Himes, 1997).

The IBW and serum albumin should form a part of the clinical assessment of pressure ulcers (Strauss and Margolis, 1996). This information gives an overall profile of the patient's condition and the severity of a pressure ulcer. Early nutritional assessment of these patients is vital, as recommended by the British Association for Parenteral and Enteral Nutrition (1994). Early treatment to rectify nutritional deficits will promote healing and reduce morbidity and mortality rates, particularly in elderly people.

CONCLUSION

The literature reveals that wound healing is very complex and correct amounts of proteins, energy, vitamins, minerals and a good blood supply are essential for the formation of collagen, allowing nutrients and energy to be carried to the wound.

More research is required as to the importance of nutritional status in patients with pressure ulcers, and also the role which proteins, vitamins and micronutrients play and the quantities of each required for healing. It appears that these roles are not fully understood.

Serum albumin is a recognized surrogate biochemical marker, offering an indication of the patient's nutritional status, but it does not provide the answer to the patient's risk of developing pressure ulcers. Serum albumin used alongside the Waterlow score will help to highlight patients who have a high risk of developing pressure ulcers (Anthony et al, 2000).

Nutrition supplementation and pressure area care will prevent unnecessary suffering from pressure ulcers. Continuous assessment of a patient's nutritional status is very important, with reassessment carried out weekly or when the condition changes (Rollins, 1997).

The nurse is the ideal person to make assessment of a patient's wound healing and then decide on appropriate nutrition, either by food or artificial means. BJN

KEY POINTS

- Patients require adequate levels of calories, protein, vitamins and minerals to support wound healing.
- Alteration in nutritional status, intake preceeding or during injury may clearly alter the normal wound healing response.
- Depending on the extent of the injury, the need for extra energy varies.
- Polyunsaturated fatty acids are responsible for integrity of the cell membrane structure and function.

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How Accurate are pressure ulcer grades? An image-based survey of nurse performance

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We report a descriptive study using a questionnaire and twelve digital photographs classified by a consensus panel of experts using the European Pressure Ulcer Advisory Panel and Stirling plus digits classifications. The expert panel comprised 5 tissue viability specialists/clinical lecturers in tissue viability with many years of collective experience and examined 30 images over $2\frac{1}{2}$ hours. In general consensus on wound grading was good; in only 2 images was there insoluble disagreement. Two hundred subjects were recruited from a Tissue Viability Society (N= 50), the European Pressure Ulcer Advisory Panel (N=50), five Community Trusts (N=50) and five Acute Trust (N=50) in England and Wales. The subjects were asked for demographic details (qualifications achieved, number of years qualified, employment grade and how their knowledge of classification of pressure ulcers has been obtained). The second part of the questionnaire asked them to classify twelve digital photographs of pressure ulcers using the European Pressure Ulcer Advisory Panel (EPUAP) and the Stirling plus digits systems. The study demonstrated that there is considerable lack of consensus when pressure ulcers are graded using the Stirling plus digit grading system and less disagreement when the EPUAP scale is used. The study also demonstrates that the statistical returns from different hospital and community units cannot be considered to be directly comparable. Furthermore, the study showed that the nurses most educated in pressure ulcer care (Clinical Nurse Specialists in Tissue Viability) were the most keen to receive extra education, whilst ward nurses were happy with their current knowledge and did not believe further education on pressure ulcer grading was necessary.

Introduction

There are approximately 16 published pressure ulcer classification systems of which 6 are in routine use[1,2]. The main area of conformity of all classification scales is that higher numbers denote more severe grades of pressure ulcer. A particular dilemma for the practitioner is not being able to recognise a pressure ulcer in its early stage and how deep this tissue damage is. It has been proposed that failure to detect pressure ulcers in the early stages may be due to a lack of clarity on how to use grading systems[2,3]. Other variables may also be responsible. There has been very little research into nurses' understanding of the classification of pressure ulcers.

Healey[5] carried out a similar study to the one reported here and examined Stirling digit 1, Torrance and Surrey grading of 10 photographs of pressure ulcers of Caucasian patients. Each pressure ulcer was graded against the Surrey, Torrance and Stirling classification systems. The least complex grading system was preferred by the nurses surveyed – 57%, 16% and 11% Surrey, Torrence, and Stirling respectively. The level of agreement found was Surrey – 67%, Torrance – 60% and Stirling – 39%.

Buntinx *et al*[6] conducted a small study of inter-observer variation in assessment of skin ulcers. Three nurses and three physicians, with chronic wound experience, studied twenty-seven skin ulcers using five classification systems to evaluate reliability and validity. It was found that inter-observer reliability was poor and further study was recommended.

Essentially, previous studies have demonstrated poor agreement between grading systems but were either small or relied on a single observer to determine what the 'correct' answer should be. We carried out a study using a set of photographs graded by consensus, but acknowledge the difficulties of grading from images. In addition, we evaluated the current levels of education and attitudes to further education on pressure ulcer grading of different groups of nurses in the hope that

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this may prove useful for health service planning in the future. To our knowledge no previous examination of nurse education in respect of pressure ulcer classification has been published.

Precision and accuracy
Assessment of a pressure ulcer grade results in a number and just as we expect a serum sodium to be 'correct', it is reasonable to expect pressure ulcer grading to be 'correct'. But what is a 'correct' result? Essentially, this is a result in which we can be confident. To achieve this, a result must be reproducible and have a constant meaning. This is usually monitored in pathology laboratories by examination of precision and accuracy. These are illustrated by the 'archer' analogy (*figure 1*).

Methods

Consensus panel
A consensus panel of experts examined 30 digital photographs and classified the images of pressure ulcers using the European Pressure Ulcer Advisory Panel and Stirling plus digits classifications. The expert panel comprised 5 tissue viability specialists/clinical lecturers in tissue viability with many years of collective experience. The panel examined the 30 images over $2\frac{1}{2}$ hours. In general, consensus on wound grading was good; in only 2 cases was there insoluble disagreement.

Nurse survey
A letter, questionnaire and twelve photographs of pressure ulcers from Caucasian patients selected from the 30 examined by the consensus panel was sent to Tissue Viability Nurses, District Nurses, Acute Hospital Nurses and European Pressure Ulcer Advisory Panel members. The subjects (N=200) were recruited from the Tissue Viability Society, the European Pressure Advisory Panel, five Community Trusts and five Acute Trusts in the England and Wales over a three-month period.

The questionnaire asked for brief details of the nurses' qualifications, the number of years since qualification and the origins of their current knowledge of classification of pressure ulcers, eg books, study days or courses. To identify whether training affected competency, the classification system currently in use was recorded together with information on quantity and quality of any training they had received on this system. The questions were based on a previous questionnaire validated by Russell[4]. Descriptions of the Stirling plus digits and EPUAP classifications were provided and nurses were asked to grade the images, using both systems.

Precision and accuracy: statistical methods
To assess precision and accuracy, the grading decision of the consensus panel was considered to be 'correct'; henceforth the term '*correct*' is used interchangeably with '*agreed with consensus panel*'. Since each image had a different grade assigned to it by the consensus panel, the variability of results was assessed by taking the difference between the grade assigned by each nurse and the consensus panel. Accuracy was assessed by calculating the mean of all differences and precision by the mean of the absolute values of the differences. Thus, a sequence of 4 results (0.4, 0.4, −0.4 and −0.4) would have an 'accuracy index' of 0 indicating that on average the assessment of grade was 'correct' and a precision index of 0.4 indicating that although the results are 'correct' *on average*, each individual value is actually at considerable deviation from the true estimate. The mean and standard deviation for the accuracy index and precision index broken down by work area of nurse and routine grading system in use was then calculated. Additionally, the proportion of images where the 'correct' 2-digit Stirling or 1 digit EPUAP grade was assigned was calculated*.

The sample population consisted of qualified nurses working in the acute and community sectors with no less than three years post qualification experience and members of the European Pressure Ulcer Advisory Panel. Nurses who had previously participated in the pilot study, or were closely associated with pressure ulcer research at Burton, were excluded.

Ethical approval
Since images of patients were to be distributed, ethical approval was sought from South Staffordshire Local Research Ethics Committee (LREC) and granted, as the study did not affect patient care and no image could result in identification of any individual.

Results

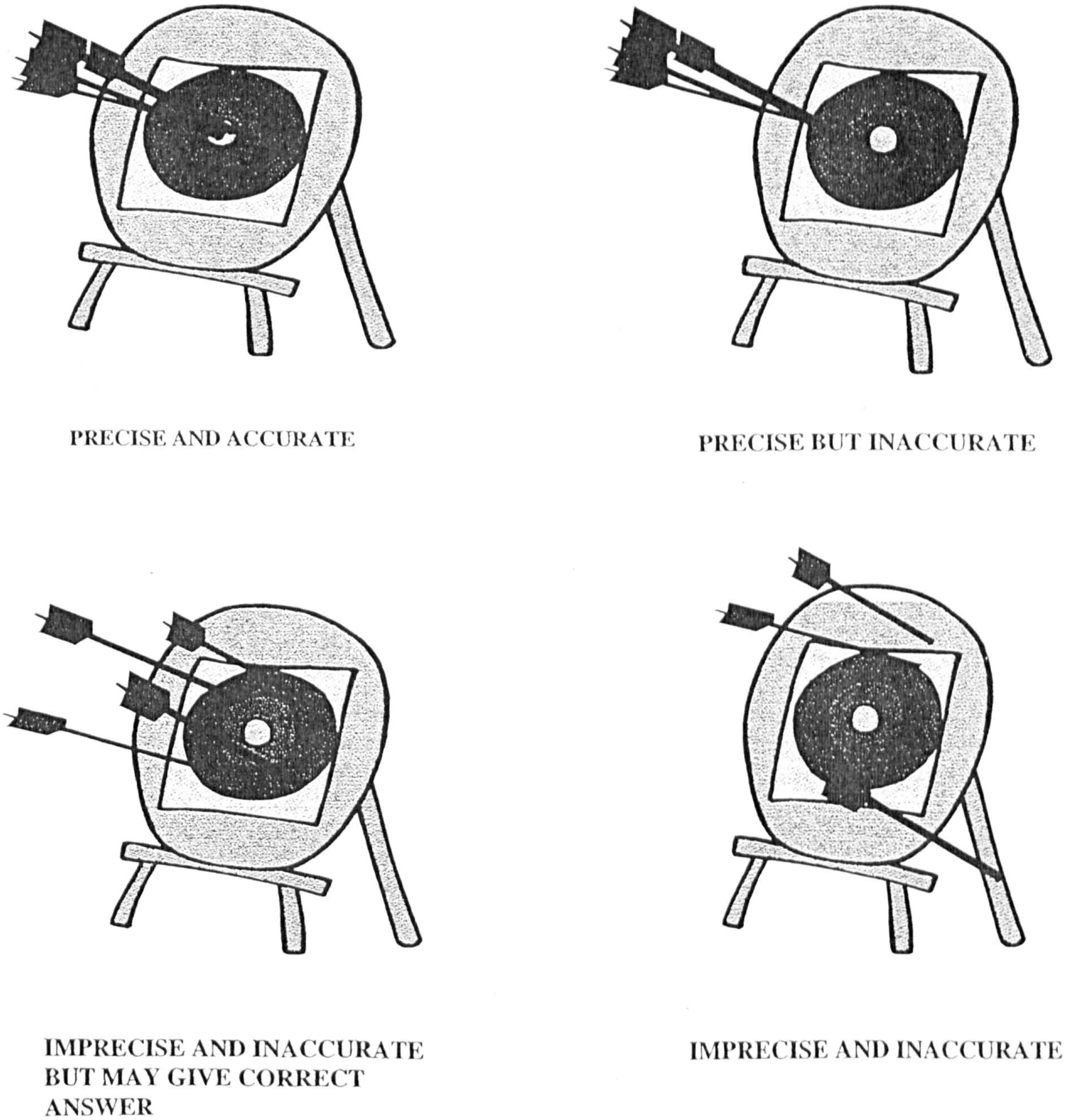
The sample replies were almost evenly distributed: 27 Clinical Nurse Specialists, 21 Pressure Ulcer Advisory Panel members, 25 acute nurses and 24 community nurses (97 replies of 200) — just under a 50% response rate. *Figure 2* shows educational qualifications by group.

The survey also enquired about other demographic features: clinical nurse specialists were grades G (22%), H (56%) and 22% I (22%); community nurses were grades D (4%), E (21%), G (50%) and H (21%); and

* It may be thought appropriate to compare the performance of each grading scale using Kappa testing. However, the Kappa test applies when the two comparator scales have the same trait prevalence (distribution) and base-rate. Since the EPUAP grade scale is the set {1, 2, 3, 4, 5} and the Stirling scale is the set {1.1, 1.2, 1.3, 1.4, 2.0, 2.1 . . . 5.4} the two are not compatible and it is not possible to calculate a Kappa statistic. The accuracy and precision index are also affected by the same 'set' problem that prevents Kappa calculation. Since the minimum increment for EPUAP is 1, the variance as a result of a 'mis-grade' is far more severe. Therefore, the most effective method of interpreting whether agreement is achieved is to examine the raw frequency of agreement.

Figure 1. Precision and accuracy — the archer analogy.

One archer hits the bullseye every time in a tight cluster [accurate and precise]; one misses the bullseye but is tightly clustered [precise but inaccurate]; one misses the bullseye with a wide spread but the average of his 4 shots is in the bullseye [imprecise but may give an accurate answer if all shots are averaged together]; and the other misses the target altogether. The ideal is the first archer but the second can be useful if the amount of his bias is constant and adjustable. The third may be useful because on average the result is in the bullseye but since we usually only make one measurement little faith can be placed in the result, so for practical purposes this archer is also useless.



acute care nurses were grades D (12%), E (40%), F (28%), G (12%) and H 8% most Pressure Ulcer Advisory Panel member's grades did not fit into the UK nursing grades scheme. Eighty-eight percent of clinical nurse specialists; 80% of Pressure Ulcer Advisory Panel members, 64% of acute care nurse and 64% of community nurses 64% had been qualified for over ten years. Community nurses had marginally more post basic training than the clinical nurse specialists.

Eight-one percent of Clinical Nurse Specialists considered their knowledge to be good[22] with 7% claiming excellent knowledge. Seventy percent of clinical nurse specialists and 76% of Pressure Ulcer Advisory panel members felt they could benefit from additional training on the classification systems whereas 92% of community nurses and 76% of acute nurses did not want further training. *Figure 3* shows the journals read by those surveyed.

Figure 2. Qualifications of nurses surveyed.

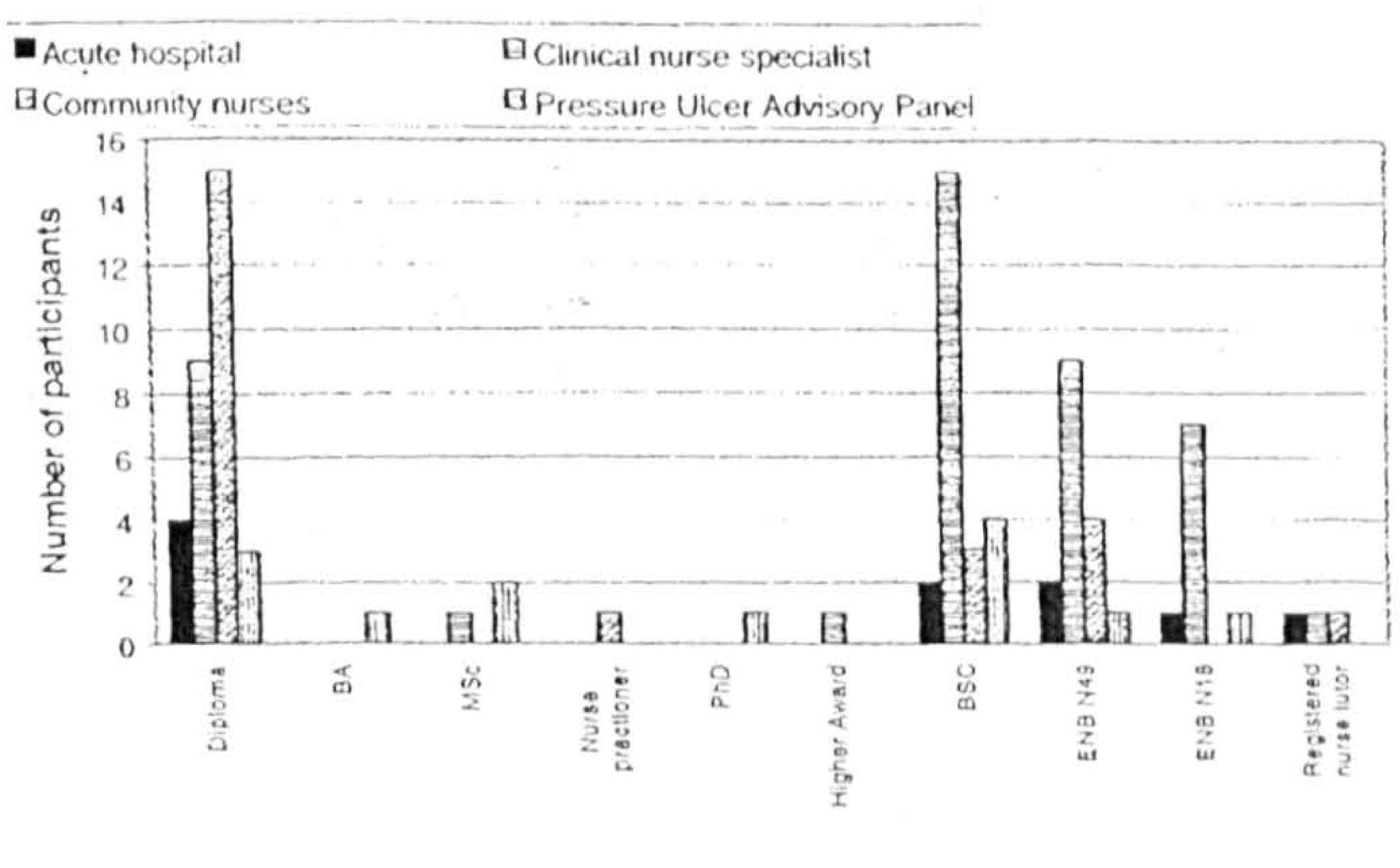


Figure 3. Journals regularly read by nurses surveyed.

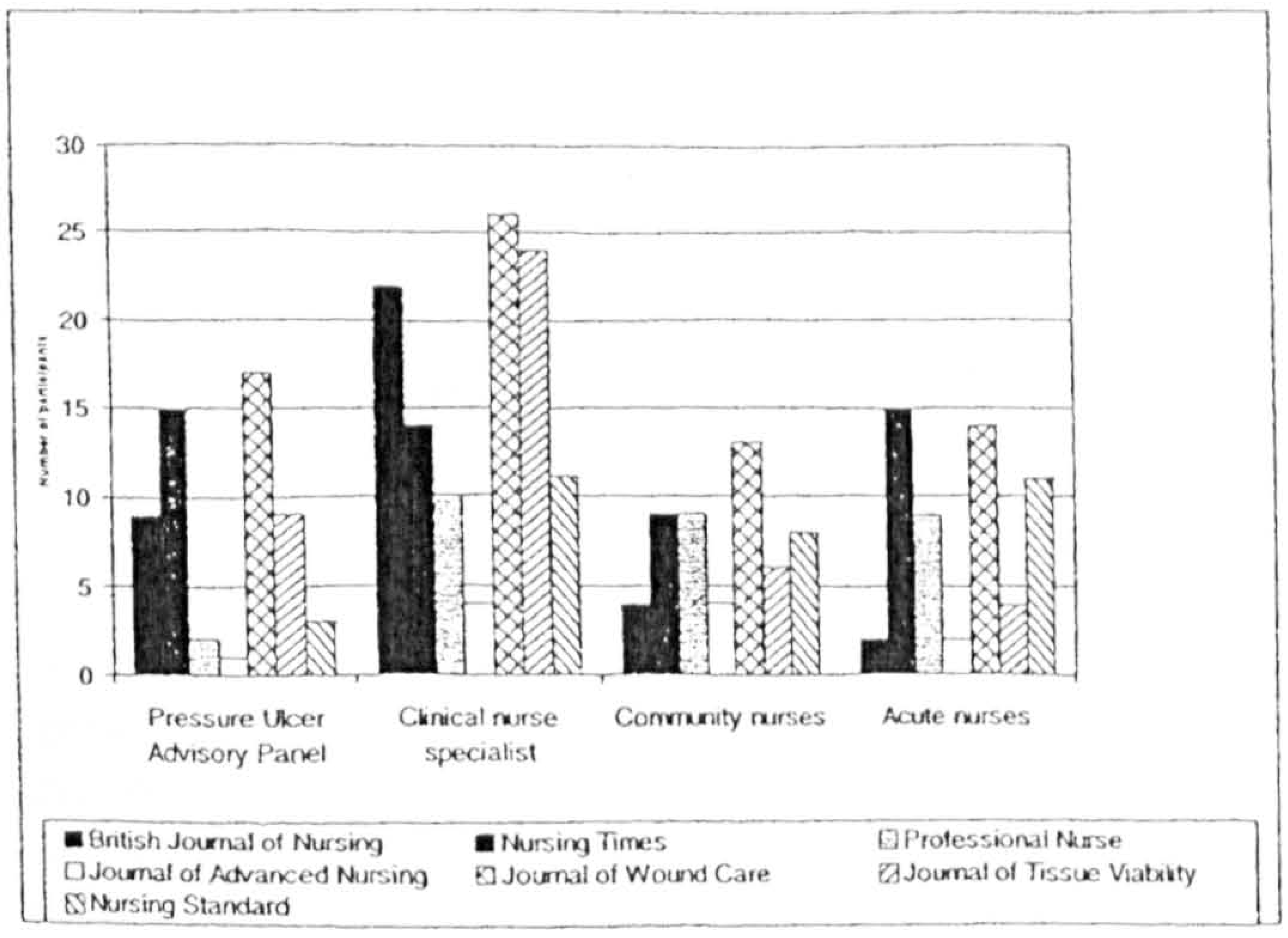


Figure 4. Bubble plot demonstrating range of Stirling grades reported. Shaded bubbles represent results in agreement with consensus panel. Bubble sizes give an impression of how many people gave similar grades.

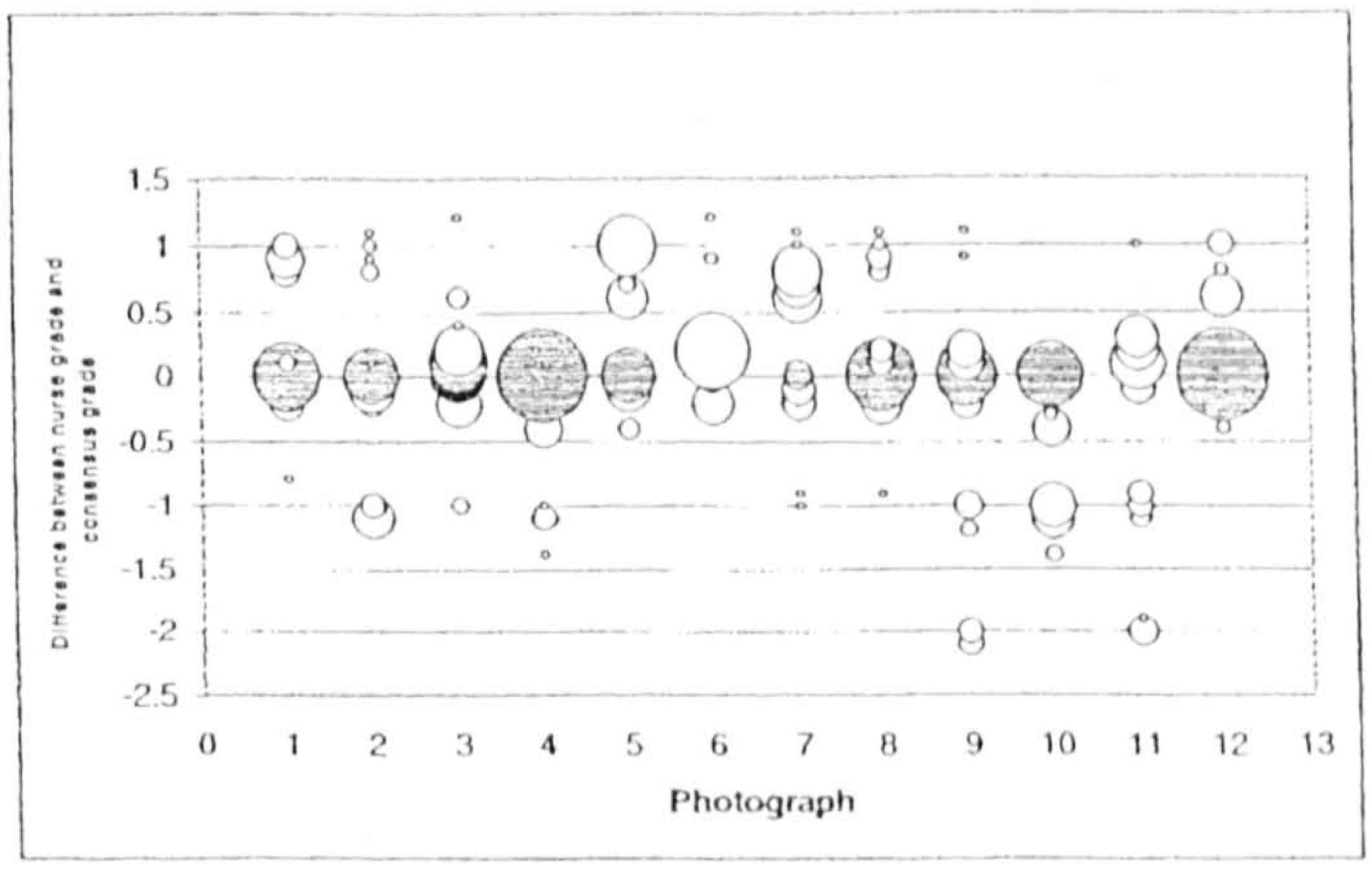
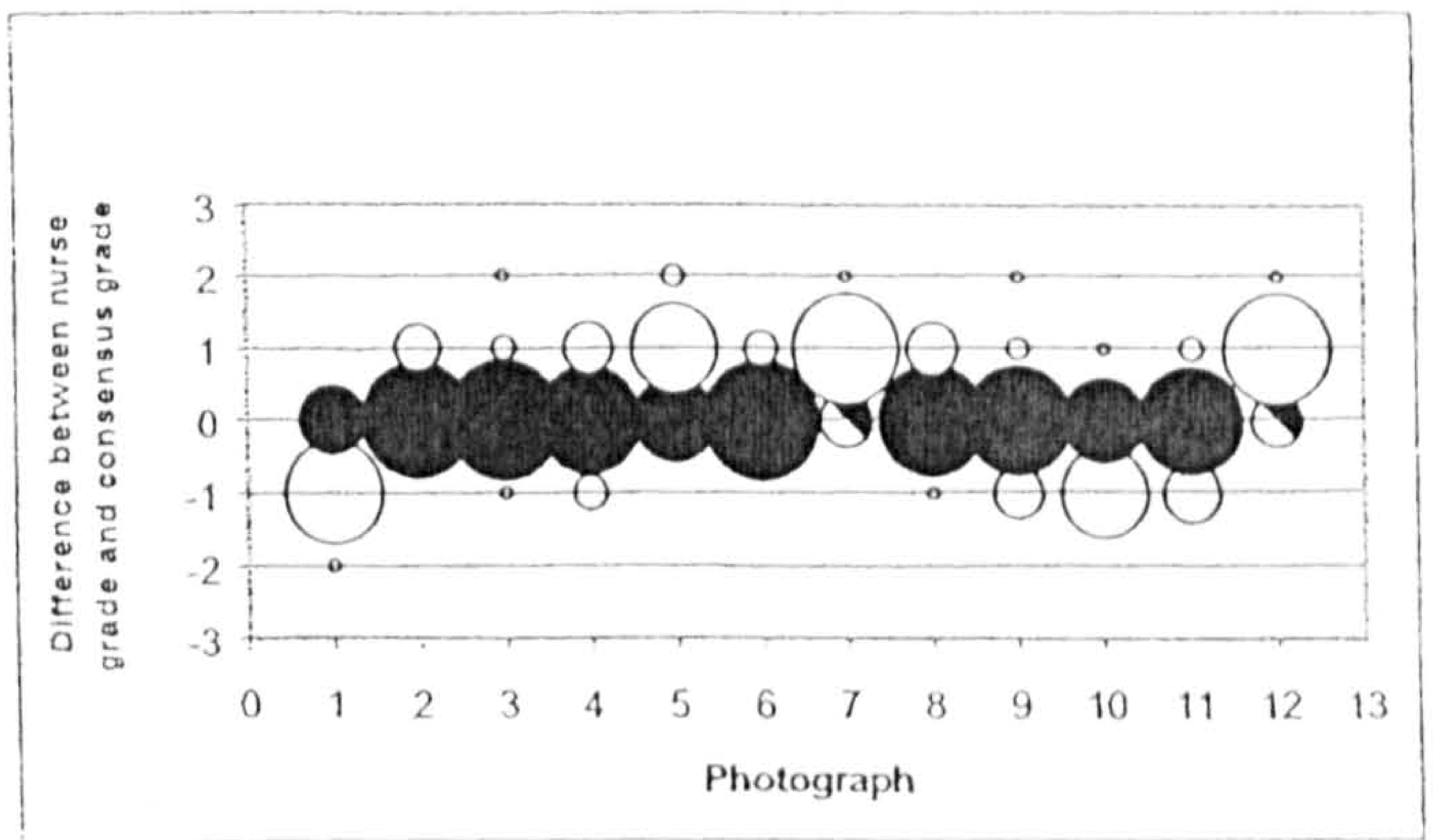


Figure 5. Bubble plot demonstrating range of EPUAP grades reported. Shaded bubbles represent results in agreement with consensus panel. Bubble sizes give an impression of how many people gave similar grades.



Nine grading systems were currently in use amongst those surveyed. The Stirling classification system was predominately used by acute care nurses, whereas the EPUAP system was predominately used by the Pressure Ulcer Advisory Panel members. The majority of the sample (93%) wished to see a national grading system adopted.

Grading of photographs

Figures 4 and *5* are bubble-plots showing the distribution of grades reported. The size of the bubble represents the number of responses at any given level.

Accuracy and precision

Figures 6a & b show the accuracy and precision indices for all replies and for 3 subgroups. The numerical results are shown in *table 1*. It is clear that on average, there is little difference between the consensus panel and the nurses surveyed. However, the precision index shows that on average there was an approximately 0.4 grade difference between the consensus panel and the surveyed nurses for the Stirling system and a 0.5 grade difference for the EPUAP system. However, one must consider this is 4 × the minimum grade increment for Stirling and 0.5 × the minimum grade increment for EPUAP. Furthermore, there were relatively few nurses currently using the EPUAP grade routinely so, with experience, it would be expected that improvement in grading accuracy would be achieved. In this light, the differences are more significant for Stirling grading than for EPUAP grading.

There is no statistically significant difference between any of the subgroups. It therefore appears that both Stirling and EPUAP indices appear to be consistent but have a wide spread — like the archer in target 3 of *figure 1*. Taking minimum increments into account, the EPUAP is relatively more consistent. This is reflected by the ability of nurses to get the same result as the consensus panel. In 30.2% of cases, the surveyed nurses gave the same 2-digit Stirling grade as the consensus panel, but using the EPUAP grading scheme 61.9% of grades agreed.

Discussion

Weaknesses of the study

In the few previous studies of pressure ulcer grading, it has been recognised that photographs are not the ideal

Figure 6a. Precision and accuracy of Stirling scoring, comparing nurses who routinely used the Stirling score with nurses who use other scoring systems. Horizontal line represents mean response and vertical bars indicate ± 1 standard deviation. There are no statistically significant differences between the performance of any subgroup.

NOTE: only 1 pressure ulcer specialist nurse used the Stirling score so no standard deviation can be calculated.

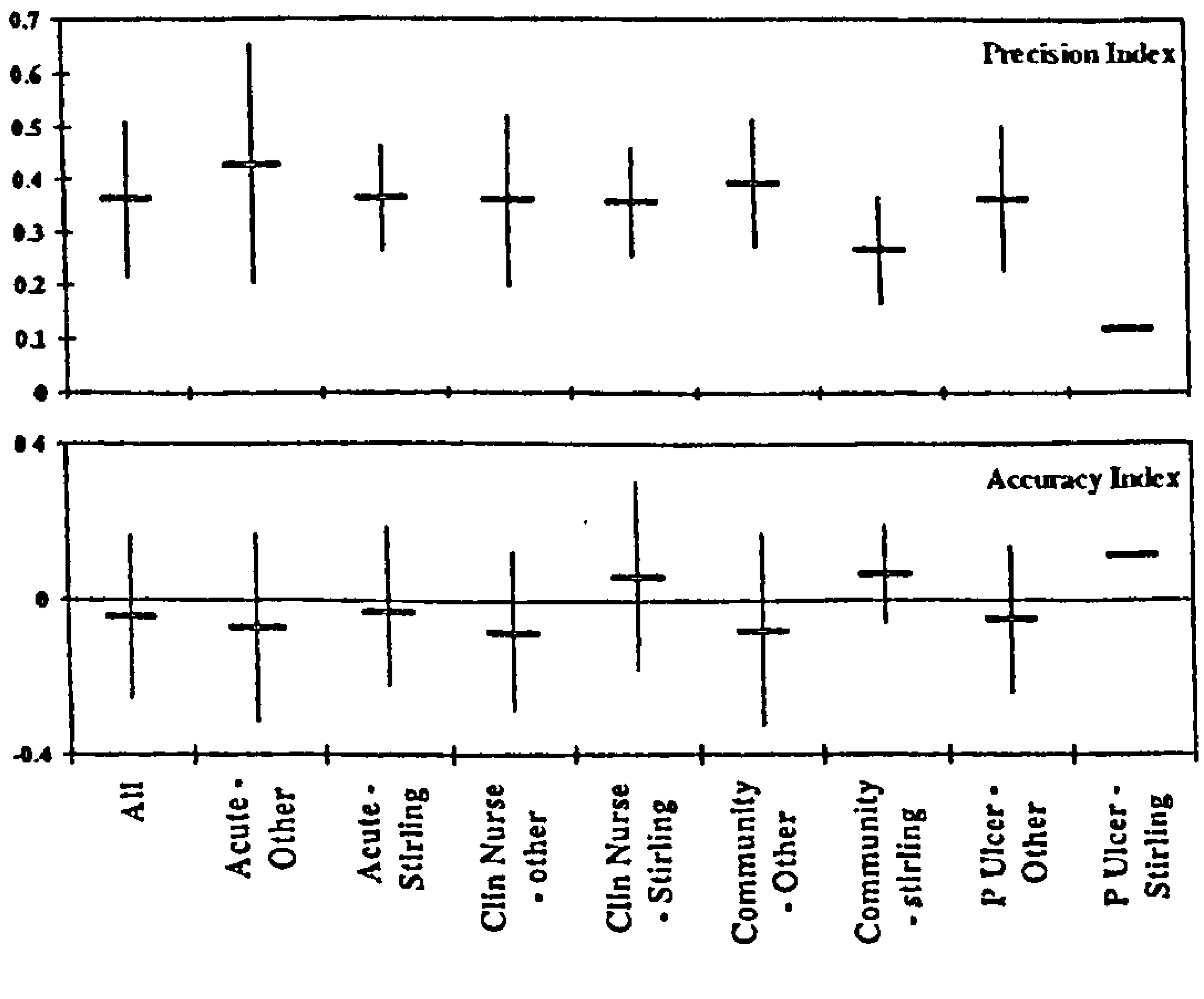
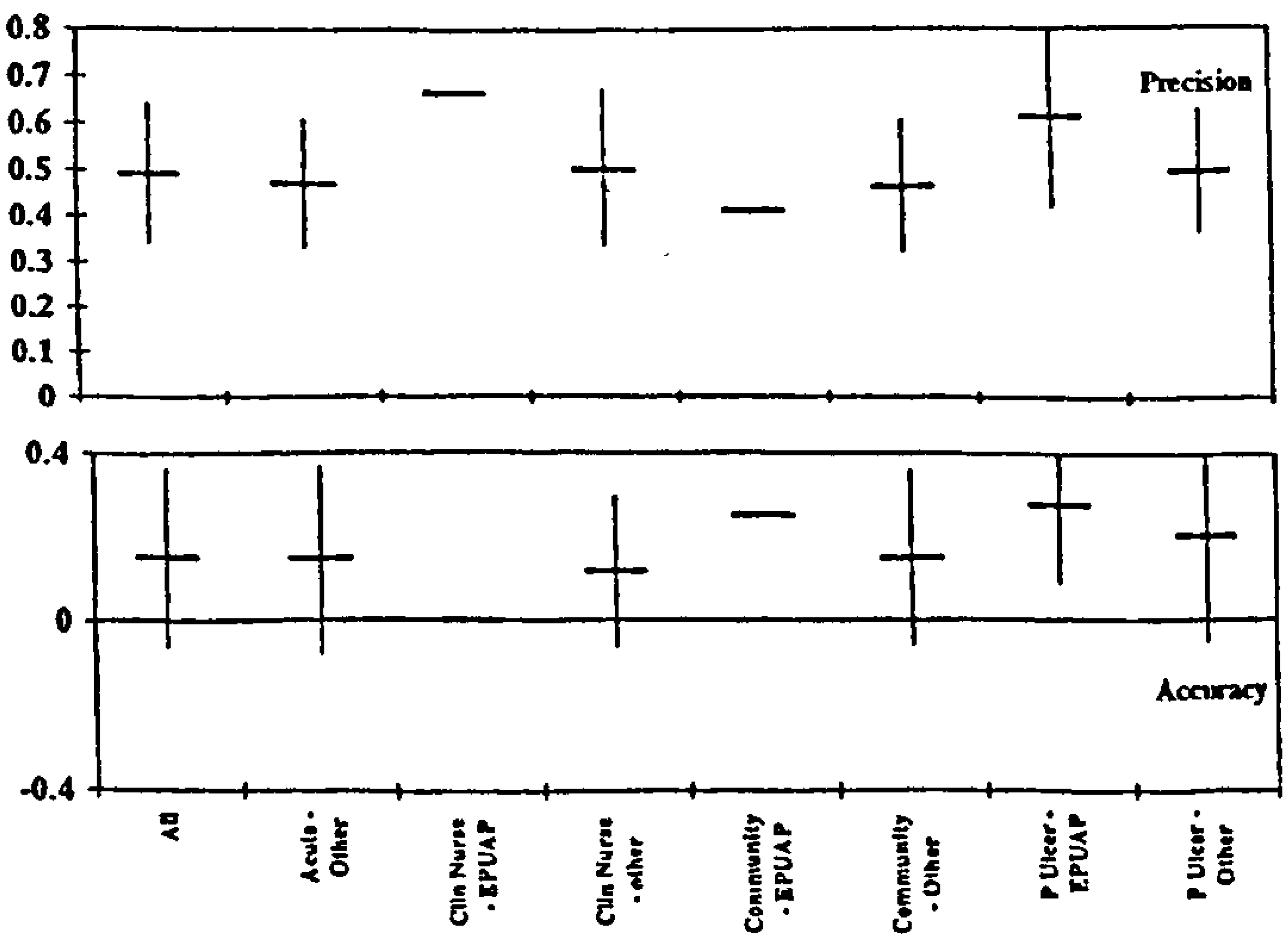


Figure 6b. Precision and accuracy of EPUAP scoring, comparing nurses who routinely used the EPUAP score with nurses who use other scoring systems. Horizontal line represents mean response and vertical bars indicate ± 1 standard deviation. There are no statistically significant differences between the performance of any subgroup.

NOTE: only 1 pressure ulcer specialist nurse used the EPUAP score so no standard deviation can be calculated.



way to determine performance and that real life observations would be preferable. However, since it is more practical to distribute images by post than patients, we used an image-based survey. This has the disadvantage that only one mode of examination (sight) is available to practitioners, and may mean that some of the discrepancies found are artefactual. The inability to calculate comparability statistics could be considered a weakness but is unavoidable. However, we believe that the large discrepancy in accuracy between Stirling and EPUAP (30.2% and 61.9% respectively), is adequate evidence of superiority of the latter.

Strengths of the study

The original 'diagnosis' of pressure ulcer grade was not the opinion of a single tissue viability nurse but was a consensus opinion of 5 specialists. A good response to the survey was received (97 replies from 200). The study also examined other aspects of pressure ulcer knowledge such as sources of information and willingness to pursue further study.

In our study, we asked for grades to be reported using the Stirling system plus all 3 digits. Only a very few nurses did this and most only gave Stirling grades with the main grade plus 1 digit. This applied equally to nurses who routinely used Stirling and those who did not and suggests that, in practice, the Stirling system is too complex. Our accuracy and precision analysis of the Stirling grades demonstrated that in general nurses did not identify the 'correct' result. Our findings corroborate Healey[2] who demonstrated that the Stirling has poor reliability, particularly when used with second digits. The EPUAP grade correlated better with the consensus panel, although some reliability problems remain.

Our results show that in general, Clinical Nurse Specialists in tissue viability are educated to high level (BSc or MSc) and are recognised by employers to be skilled as evidenced by their relatively high salary grades (22% on G grade, others higher). Other staff groups were also graded appropriately. Most of the nurses surveyed had been qualified ten years or more, but it should be borne in mind that this does not always mean that training has been undertaken recently. It is known that post-basic education on pressure ulcer prevention is seen frequently as low priority[4,7]. Most clinical nurse specialists considered themselves knowledgeable but believed further education would be valuable. Overall, the less-specialised nurses did not believe extra education on pressure ulcer grading would be of value. This is significant, because the majority of gradings are carried out by ward staff and not by nurse specialists and we have demonstrated a significant lack of consensus in pressure ulcer grades given by this group. However, this is not surprising given that pressure area care makes up only a small part of the general nurse's duties and time has to be allocated to education in other areas also.

This also calls into question the function of grading itself: are grades identified simply to enable comparative statistics to be generated, as they appear to have little clinical relevance? There is no research evidence to suggest that grading pressure ulcers has any impact on patients' outcomes or anything else. In 1986, it was claimed that nurses failed to put research evidence into

Table 1. Precision and accuracy estimates.

	Accuracy	Precision	N	Accuracy	Precision	N
Stirling grading						
All nurses	−0.045 ± 0.21	0.36 ± 0.15	85			
	Stirling users			Non-Stirling users		
Acute ward nurses	−0.030 ± 0.22	0.36 ± 0.10	11	−0.073 ± 0.25	0.43 ± 0.22	10
Clinical nurse specialists	0.065 ± 0.24	0.36 ± 0.10	6	−0.082 ± 0.21	0.36 ± 0.16	21
Community nurses	0.067 ± 0.13	0.27 ± 0.10	7	−0.076 ± 0.25	0.39 ± 0.12	13
Pressure ulcer advisory panel members	−0.1	0.12	1	−0.051 ± 0.19	0.36 ± 0.14	16
EPUAP Grading						
All nurses	0.15 ± 0.21	0.49 ± 0.15	86			
	EPUAP users			Non-EPUAP users		
Acute ward nurses				0.15 ± 0.22	0.47 ± 0.14	20
Clinical nurse specialists	0	0.67	1	0.12 ± 0.18	0.51 ± 0.17	26
Community nurses	0.25	0.42	1	0.15 ± 0.21	0.46 ± 0.14	19
Pressure ulcer advisory panel members	0.28 ± 0.19	0.61 ± 0.19	3	0.20 ± 0.25	0.49 ± 0.13	16

practice because of a lack of educational opportunities[8]. Since then, study opportunities in terms of course availability have increased in numbers but availability of study time has not and may even have been reduced as workload has increased whilst staffing levels have decreased. To improve grading consensus or to introduce a National grading scheme, education sessions will be necessary — but it is first necessary to convince nurses that specific education on pressure ulcer grading is valuable, as compared with education about other clinical problems[9]. Whether it is appropriate for nurses to collect statistical data of minimal direct clinical relevance is debatable.

Another major problem arising from the lack of consensus on grades is that prevalence and incidence data collected for Health Authority and Primary Care groups will not be dependable. The Government believes league tables are helpful because by 'naming and shaming' poor performers, they can be encouraged to improve[10]. When performance data is as variable as our survey suggests, it becomes difficult to trust the raw data, and hence any league table derived from it. This problem has already been noted for pressure ulcer rate comparisons[11].

We therefore echo and amplify previous calls for a National grading standard[2,12], introduced with sufficient education to ensure that agreement is maximised. However we also advise caution. Pressure ulcer grading using a numerical system has some drawbacks: a grade 4 sore is not necessarily twice as bad, or twice as big or twice as anything as a grade 2 sore. It is possible that large 'low grade' sores may be upgraded to indicate the degree of clinical significance, and vice-versa for small 'high grade' sores. Furthermore, the site of an ulcer may have clinical significance. However, attempts to synthesise these aspects into a grading system appear to lead to imprecision.

Further research to investigate mis-reporting of current grades, non-numerical scales, the importance of superficial and full-thickness lesions and the significance of blanching/non-blanching erythema may all shed light on this complex area.

Conclusion

The purpose of a grading system is to enable communication between professionals using a common scale on which it is believed like always equals like. Neither of the classification systems used in this study was completely reliable and accurate. The EPUAP system was simpler and more accurately used than the Stirling system but gives little useful clinical information. The significant variation demonstrated here indicates that the Stirling score fails to achieve the commonality of interpretation that is essential for meaningful comparison to be made.

This study has many implications.

- Classification of pressure ulcers is not easy.
- A simple grading system such as EPUAP generates more consensus than a complex system. However, if one were to consider that this demonstrates that EPUAP is 'better' than the Stirling system, it still does not demonstrate that it is the 'best' grading system as there are many alternatives that have not been considered. Further research to develop an 'ideal' system would be required, if a national system is thought desirable.
- Clinical nurse specialists in tissue viability are highly educated but believe they should continue to learn pressure ulcer grading.
- Any grading system must be cascaded down to the nurses at ward level to enable audit.
- The reluctance expressed towards more education on

pressure ulcer grading at ward level may in future hinder change and introduction of yet another different grading system in the future.

Although a perfect grading system may be impossible to achieve, we need to continue to work towards understanding what a grading system should provide and how this can be achieved.

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